PHYSIOLOGICAL PSYCHOLOGY

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which indicates that some of the mental processes, such as the affections, are located in the heart. When we talk about a man's being faint-hearted, or chicken-hearted, or big-hearted, we imply the same thing. The words courage and courageous contain the French word for heart, and imply that the heart is the seat of this feeling. Likewise, when we speak of the opposition between the head and the heart, we indicate that the intellectual processes are located in the head, but the feelings are located in the heart.

The Blood.—When two men are angry, we sometimes hear that there is bad blood between them. Some persons are said to be blue-blooded, or hot-blooded or cold-blooded, which seems to imply that certain of the mental characteristics are associated with the blood.

The Liver.—Melancholy, choleric, and choler imply that some of the mental processes are dependent upon the liver. So we understand when jealousy is personified as the green-eyed monster, that the excessive secretion of bile, which is a symptom of the disease called jaundice, and which promptly shows itself in the greenish coloring of the whites of the eyes, is likewise associated with certain of the feelings. Occasionally we read in literature of one's "venting his spleen," which indicates that the organ named is the seat of some of the mental processes.

The Breath and the Lungs.—But the words spirit and inspiration imply that the lungs, or the breath constitutes the real location of the soul, or the essential part of man.

The word spirit means breath, so when we say that the spirit has left the body we mean to assert that the breath and the lungs constituted the location of all that made mental action possible.

The First Line of Evidence.—However, we now believe that no other part of the body is so closely connected with any mental process as are the brain and nervous system. There are four distinct lines of evidence that lead us to that conclusion. First, the brain of man is larger than the brain of any other animal. The thinking capacity of man is greater than the thinking capacity of any other animal. Consequently we are inclined to believe that there must be some kind of a relation between the large brain and the large thinking capacity.

Conclusion Probable Only.—From the way in which our conclusion is drawn, it will be impossible to assert that the large brain is the cause of the large thinking capacity, or that the large thinking capacity is the cause of the large brain. All that we can assert is that there is probably some connection between the large brain and the large thinking capacity.

Brain of the Elephant and the Whale.—Man has a larger brain than any other animal except the elephant and the whale. Why, then, do not the elephant and the whale surpass man in their ability to think? The great size of the body of the elephant and the whale makes a great demand upon the nervous energy of these animals in order to move the muscles. So, while the large brain

generates a vast amount of nervous energy, so much is employed in moving the muscles that there is not a large surplus to be employed in thinking. In this way we may account for the large brain of the elephant and the whale and their relatively smaller amount of intelligence.

Size of the Brain.—We may consider two pounds as about the minimum weight of the human brain, and four pounds as the maximum, although a very few brains have been weighed of more than four pounds, and in one or more cases, as much as five pounds. If the brain grows to be no larger than two pounds, the person either dies or is a microcephalic idiot. More than ninety-nine persons in a hundred have brain weights between two and a half, and three and a half pounds. For men, the average brain weight is about three pounds and two ounces; while for women, it is about two pounds and thirteen ounces. The weight of the elephant's brain is from six to eight pounds, while the largest whales may have a brain weight of even more. However, no other animal than the elephant and the whale has even approximately so large a brain weight as does man, notwithstanding the body weight may be much greater.

Second Line of Evidence.—The second reason is very nearly like the first. The relative proportion of brain weight to weight of body is greater in man than in any other animal (with very few exceptions). The thinking capacity of man is greater than that of any other animal. Hence we are inclined to believe that the great thinking capacity is in some way associated with the great relative proportion of brain weight.

Proportion of Brain Weight.—In man, the brain constitutes about one-fiftieth of the weight of the body. A person who weighs two hundred pounds ought, then, to have a brain weight of about four pounds, while the person who weighs one hundred pounds ought to have a brain weight of two pounds. The fact is that the very heavy men, two hundred pounds or more, are not likely to have a brain weight of four pounds. Consequently their proportion of brain weight to weight of body is less than one-fiftieth. A small person is likely to have a much greater brain weight than two pounds, so his proportion will be greater. Also, it is true that on the average, the proportion of brain weight to weight of body in women is greater than it is in men. But any person of average body weight, say 140 or 150 pounds, is likely to have a proportion of brain weight not varying widely from one-fiftieth.

Brain of Mouse and Sparrow.—In the mouse, sparrow and some very small monkeys, the proportion of brain weight to weight of body is greater than it is in man. It seems as if there must be a brain of a certain size to permit such an organization of nervous tissue as will constitute a brain and do the work that a brain must do.

Third Line of Evidence.—A third reason for believing that the brain is more intimately connected with mental processes than is any other part of the body may be stated as follows: The brain of a human being manifests a greater degree of complexity than does that of any other animal. The thinking processes of man are more complex than are the thinking processes of any other

animal. Hence we are inclined to believe that the complexity of brain structure is in some way related to the complexity of thought. Let us look at the brain to see how complex its structure is.

Parts of the Brain.—The brain is composed of three parts—cerebrum, cerebellum and medulla. It has been supposed that these three parts are homologous to the three forward ganglia of the nervous system of an insect or other arthropod. If we examine the nervous system

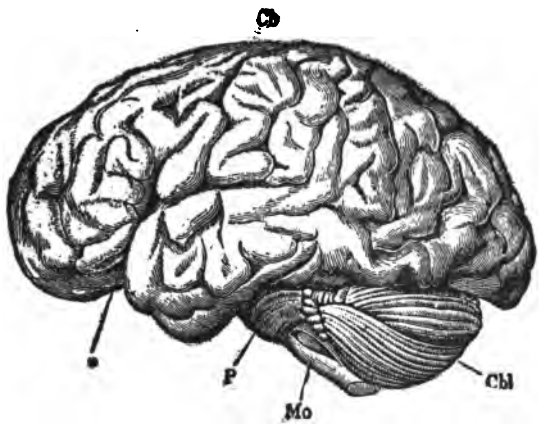


Fig. 1—The Brain: Cb, cerebrum; Cbl, cerebellum; Mo, medulla.

of a caterpillar or a grasshopper we shall find that it is composed of a chain of nervous knots, or ganglia, which are connected by a double nerve cord. If we imagine the three forward ganglia to become very much enlarged, the third to become more enlarged than the others behind it, the second more than the third, and the first more than the second, we shall have something similar to the

arrangement that we find in the cerebrum, cerebellum and medulla. Especially if we understand that the three enlarged ganglia have pressed upon each other to such an extent that they have been crowded out of a straight line, and the forward one bent down at an angle with the others.

The Brain as a Series of Ganglia.—In the brain of a fish, frog, and other animals not so complex as mammals, we shall find other parts of the brain that are very conspicuous. In the brain of a fish, two large, rounded lobes lie between the cerebrum and the cerebellum. These are known as the optic lobes and are perhaps of more importance to the fish than are the cerebral lobes themselves. In the frog and other animals we find two other lobes very conspicuous, lying in front of the cerebrum, from which nerves lead to the organs of smell. These are the olfactory lobes. We can find in the human brain the homologues of both the olfactory lobes and the optic lobes, but they are very small compared with the cerebrum. But if we were to adopt the theory that the brain is composed of a series of ganglia homologous to the ganglia of an insect nervous system, we should be compelled to recognize five ganglia instead of three. This very attractive theory of brain origin was proposed by Goethe, but there is good evidence to show that it cannot be true. The brain and nervous system of a vertebrate are probably not at all homologous to the double nerve cord and ganglia of an insect.

The Cerebrum.—The cerebrum constitutes about seven-eighths of the brain, and greatly overlaps the other

parts. The cerebrum is the part of the brain that is most intimately connected with mental processes, and for us it is the brain, although the other portions have their own functions without which mental and physiological processes could not be carried on.

The Hemispheres.—The cerebrum is divided into two parts, or hemispheres, by a deep fissure, or groove, which runs from the front to the back, and is called the longitudinal fissure. The two hemispheres are designated as the right and left, and the left is usually the larger. This is associated with the fact that the larger number of persons are right handed. At the bottom of the longitudinal fissure is a mass of white fibers connecting the two hemispheres, and this portion is called the corpus callosum.

The Brain Membranes.—The surface of the brain is covered with a thin membrane which closely invests the brain substance, and is called the pia mater. The skull is lined with a tough, dense membrane called the dura mater. Between the pia mater and the dura mater is a very thin membrane, scarcely noticeable, called the arachnoid membrane, or spider web.

Convolutions and Fissures.—The surface of the brain is not smooth, but is ridged, and convoluted and thrown into folds. The grooves that run over the surface are called sulci, or fissures. Groove, sulcus and fissure are three words all meaning the same thing. Between the fissures are ridges, or gyri, or convolutions. Ridge, gyrus, and convolution are three words all meaning the same structural feature of the brain surface.

The Cortex.—In the brain we find two kinds of matter, gray and white. In the cerebrum, the gray matter is on the outside, and constitutes a layer about one-tenth to one-eighth of an inch thick. This layer of gray matter is called the cortex, and is believed to be the portion of the cerebrum that is most intimately associated with mental processes. It really constitutes the essential part of the cerebrum. It is a very complex structure, and a section of it shows five distinct layers of brain cells.

The Cortical Surface.—The cortex dips down into the fissures, and thus its extent is about twice as great as it would be if the surface were smooth. It looks as if the folding of the brain surface were a device for furnishing to the cortex a greater surface over which it may be spread. It seems as if the cortex had expanded to such an extent that there was not room for it, and it had been crumpled and folded in order to adjust its great extent to the limited space inside the skull.

Fissure of Sylvius.—Some of the fissures and convolutions on the brain surface are important for us to notice. The largest and deepest fissure is the fissure of Sylvius. It begins on what we may call the lower edge of the brain and runs backward and upward. It seems to have been produced by the folding of one portion of the cerebrum upon another, and this is really the case. The portion of the cerebrum just below this fissure is called the temporal lobe.

Fissure of Rolando.—Another fissure that is of im-

portance to us is the fissure of Rolando. This begins near the top of the brain and runs downward and forward. It is about three and a half inches long, and is of importance to us because it constitutes the axis of the motor area of the brain. Whenever a muscle of the body is moved, the nervous impulse that causes the muscle to contract starts from some place in the brain, one side or the other of the fissure of Rolando.

How Located.—We may indicate the position of the fissure of Rolando from the outside of the skull in the following manner: Draw a line on the skull from the glabella, which is the point at which the nose seems to begin, backward to a rounded prominence at the base of the skull, which is called the inion. Mark a point half an inch back of the middle of this line.

Next take a piece of paper with a square corner, presenting an angle of ninety degrees, and fold this angle into equal parts; each part then has an angle of forty-five degrees. Fold one of these forty-five degree angles into two parts each of which will be twenty-two and a half degrees. One angle of forty-five and one of twenty-two and a half makes an angle of sixty-seven and a half degrees.

Place the point of the paper so folded at the point half an inch back of the middle of the line joining the glabella and the inion, placing the straight side of the paper on the line, and the other edge will project downward and forward at an angle of sixty-seven and a half degrees. This will indicate the position of the fissure of Rolando.

The Lobes of the Brain.—These two fissures enable us to indicate the grand divisions of the surface of the hemispheres. The portion of the cerebrum below the fissure of Sylvius is called the temporal lobe. The portion in front of the fissure of Rolando is called the frontal lobe. The portion of the cerebrum at the back of the brain is

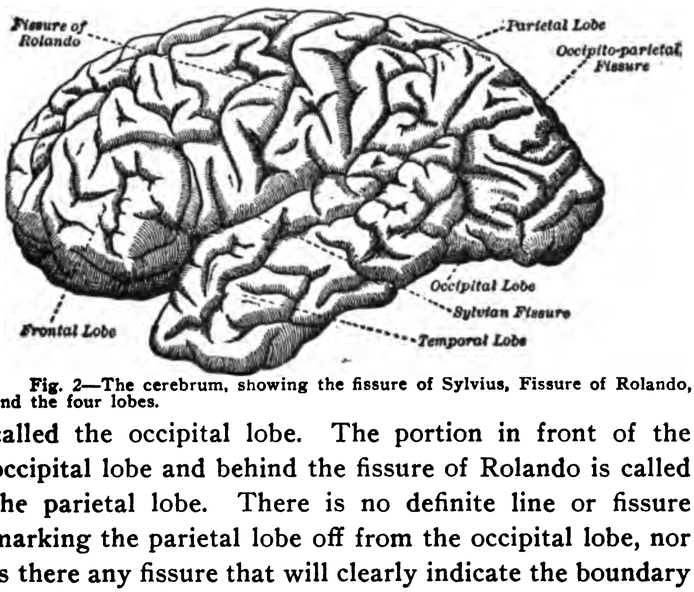


Fig. 2—The cerebrum, showing the fissure of Sylvius, Fissure of Rolando, and the four lobes.

called the occipital lobe. The portion in front of the occipital lobe and behind the fissure of Rolando is called the parietal lobe. There is no definite line or fissure marking the parietal lobe off from the occipital lobe, nor is there any fissure that will clearly indicate the boundary line between the temporal and the occipital lobe, nor between the temporal and the parietal.

DEFINITIONS

Cortex—The outside layer of gray matter of the cerebrum.

Cerebrum—The largest of the three divisions of the brain.

Cerebellum—The little brain; the second division of the brain.

Fissure—A groove, or depression upon the surface of the cerebrum.

Convolution—A ridge, or portion of the cerebral surface between two fissures.

Glabella—The place at the front of the skull at which the nose seems to begin.

Inion—The rounded prominence at the base of the skull behind.

Corpus Callosum—A mass of connecting fibers at the bottom of the longitudinal fissure connecting the hemispheres.

Hemisphere—One of the two divisions of the cerebrum.

Fissure of Sylvius—The largest and deepest fissure of the cerebrum.

Fissure of Rolando—The fissure on the side of the cerebrum that constitutes the axis of the motor area.

Pia Mater—The membranous covering of the brain.

Dura Mater—The membrane lining the skull.

Arachnoid—The spider-web-like membrane lying between the pia mater and the dura mater.

CHAPTER II

LOCALIZATION OF FUNCTION.

If, as has been set forth in the preceding chapter, all mental states are effects of physical causes, it follows that what are called mental faculties and operations are properly cerebral functions, allotted to definite, though not yet precisely assignable parts of the brain.—*Huxley, Hume, p. 105.*

There is strong reason to believe that, corresponding to the four primary taste sensations, there are separate centers and nerve fibers, each of which when excited gives rise only to its appropriate taste sensation.—*American Text Book of Physiology, Volume II; p. 412.*

In a good brain or a good machine power may thus be developed over a large surface and applied to a small one.—*Stanley Hall, Adolescence, Volume I, p. 163.*

The psychologist who has not prepared himself by a study of the organism has no more right to be heard upon the genesis of the psychical states, or of the relations between the body and the mind, than one of the laity has a right to be heard upon a question of medical treatment.—*Lewes, Problems of Life and Mind, Second Series, p. 4.*

Localization of Function.—Our fourth reason for believing that mental processes are more intimately connected with the brain and nervous system than with any other system of organs in the body, is found in the doctrine of localization of function. Briefly stated, this doctrine asserts that every portion of the brain has its own function to perform, and that no other portion can or does perform that function. It asserts that for every mental process there is a corresponding physiological change which occurs in some particular portion of the

brain and not in a different portion. It asserts that the same mental process is always accompanied by the same physiological change in the same portion of the brain.

The Doctrine Recent.—This doctrine is a matter of comparatively recent demonstration. Formerly, it was asserted that whenever a mental process was experienced the whole brain worked, and that it was impossible to conceive of merely a portion of the brain's being involved. However, the fact that the brain manifested different parts seemed to indicate that the different portions were likely to be associated with different functions. The text-books on physiology that were made and in use fifty years ago taught that the cerebrum was the portion of the brain immediately concerned in the intellectual processes, that the cerebellum was chiefly concerned in movement, while the medulla presided over the vital functions; heart beat, respiration, digestion, etc.

Phrenology.—The people who first asserted emphatically the doctrine of localization of function were the phrenologists. The doctrine of phrenology was elaborated by two German physicians, Gall and his disciple Spurzheim, who died in 1828 and 1832 respectively. They believed that the different faculties of the human mind were located in different parts of the brain, and proceeded to discover their location. When they observed a man who had some pronounced mental characteristic they examined his skull, and if they found some portion of it that seemed quite fully developed, they assumed that this portion of the skull indicated the situation of the dominating mental faculty in the brain. The popular statement of

this is that phrenology delineates character by feeling the bumps on a man's head.

The Errors of Phrenology.—We now know that this cannot be true. In the first place the skull is a double layer of bone, and between the two tables, or layers, is a more porous layer. The two tables are symmetrical; wherever we find a thickening of one, we shall nearly surely find a corresponding thickening of the other. A protuberance outward on the outer table would indicate a corresponding protuberance inward, on the other. Hence, if the reasoning of the phrenologists were correct, a bump on the outside of the skull would correspond to a depression on the brain under it.

Brain Does Not Fill the Skull.—More than this: The phrenologist assumes that the brain fills the skull, and that the shape of the skull is determined by the shape of the brain, and by its pressure on the inside of the skull. If this assumption were true, everybody would be an idiot instead of only some persons. The brain does not completely fill the skull. There is always a small space that affords opportunity for variation in the quantity of blood carried to the brain, and for brain movements. Pressure on the brain always results disastrously.

Effect of Pressure on the Brain.—A case reported a few years ago will illustrate the point. An idiot, or feebleminded boy, was examined by physicians. They diagnosed the feeblemindedness as arising from the fact that the skull was not growing fast enough to afford room for the growth of the brain, and therefore was exerting

pressure upon the brain. So they sawed through the skull and permitted the brain to expand, which relieved the pressure and cured the feeblemindedness. It is unnecessary to say that this account is extremely improbable, but it will illustrate the principle as well as if it were true. If anything ever happened that way that is just about the way that it would happen.

Phrenologists' Location of Faculties.—The phrenologists located in different parts of the brain such faculties as language, patriotism, benevolence, firmness, love, hate, form, economy, locomotion, and many other so-called faculties which have no existence in that sense. We know that there is no center for memory nor for reason, and no center for nearly every faculty that the phrenologists located. In not a single instance has the location of any faculty by phrenologists been confirmed by the later investigations which have led to the adoption of the doctrine of the localization of function as at present understood.

Stimulation.—There are four distinct lines of evidence by which the doctrine of localization of function has been established. The first consists of the results of experiments upon the brains of monkeys. The brain of a monkey is so nearly like the brain of a human being that what is true of a monkey's brain may be assumed to be true, with modifications, of the human brain. A monkey is chloroformed, the brain exposed, and the pole of an electric battery is applied to a small spot on the surface of the brain. If the pole is applied to some portions of the

brain, there will be no indication of any change; but if it is applied to a spot in the Rolandic area, there will be a

Fig. 3—Left hemisphere of a monkey's brain showing the location of the motor centers.

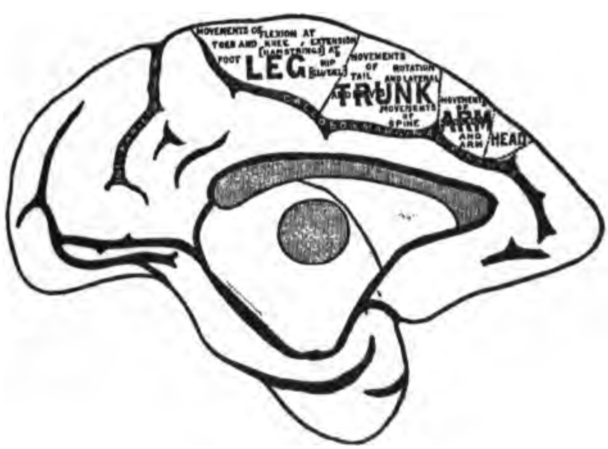


Fig. 4—Medial surface of monkey's brain showing location of the motor centers.

movement of some part of the body. If the pole is applied to a spot near the lower part of the fissure, some muscle of the face will move. In this way the whole Rolandic area has been mapped out, and the center for almost every muscle has been determined.

To What Applicable.—This method is applicable to the determination of the motor centers, but not to any other. If the pole of the battery were applied to some spot in the sight center, there would be no way of telling whether the monkey were seeing or not. Nor, if we were to suppose that there is a memory center, when the pole of the battery should be applied to it, would there be any way of indicating that the monkey remembered.

Hospital Cases.—The second line of evidence is derived from the records of hospital cases. As soon as the monkey's brain had been mapped, physicians, or surgeons, began to apply the results to the treatment of cases of brain disease. Not many years ago, it was believed that a mere puncture of the brain was sufficient to cause death. Now it is known that the brain may be cut and portions of it removed with less danger than attends an operation upon the abdominal organs. We have reports of thousands of cases in which surgeons have diagnosed a disease from the derangement of some muscular function, and have cut into the brain, removing tumors, clots of blood, and pieces of bone. A single case will suffice as an illustration, a popular account of which will be found in Harper's Magazine for June, 1893.

The Mill Girl Case.—In 1891, a mill girl in Philadel-

phia was treated by a physician for epilepsy. She had a fit several times a day. She knew when a fit was coming on by a numbness which appeared first in her right thumb, then spread to her arm, soon after which she would become unconscious. Before she began to have fits, she had a numbness in her thumb, which gradually became more pronounced until the fits began to appear. The surgeons reasoned as follows: "The cause of the fits is a disease in the brain. Evidently the disease began in the center of the thumb, although it has now doubtless spread to surrounding centers. If we can cut out that portion of the brain which constitutes the thumb center we shall remove the portion that is most seriously diseased, and will alleviate, even if we do not cure, the disease."

Delicacy of Determination.—They located the fissure of Rolando, removed a button of bone, exposed the brain in the region in which they knew the thumb center must be situated, and then proceeded to determine accurately its position. It was the right thumb, so the left side of the skull was opened. The pole of a battery was applied to various places until the thumb center was definitely determined. It was necessary to be thus accurate in its determination, for if the cut should be made too far in one direction, the entire hand would be paralyzed, and the girl unable to continue her work. If it was made too far in the other direction, the organs of speech would be paralyzed and the girl would be unable to talk, an exceedingly serious matter for any woman.

Effect of the Operation.—A small portion of the cortex

corresponding to the thumb center was removed, the pole of the battery applied to the edges of the cut until it was certain that all of the thumb center was gone, while the hand and speech centers were intact, the wound was closed up and the girl recovered. While before the operation she had several fits a day, after the operation she had a recurrence of only seven fits in eight months.

Recovery of Function.—She resumed her work. At first her thumb was completely paralyzed, but in the course of several months, she gradually recovered the power to use it. This peculiar phenomenon is sometimes adduced as an argument against the truth of localization. There are several possible explanations of the recovery of function, none of which is perfectly satisfactory. The first and the most natural one is that cells that have been removed by the operation were replaced by growth, as a portion of the skin will be restored when it has been removed. This explanation is obviously not the correct one, for nerve tissue when once destroyed will not be regenerated.

Explanation of Recovery.—The second supposition is that when the thumb center on the left side of the brain had been removed, the corresponding center on the right side took up the function of that on the left. This is almost certainly not true. The third supposition is that some undeveloped cells in proximity to the center that has been removed become developed, form a connection with muscles whose nervous connections have been cut away, and really constitute a new center. This is the

most probable of the three suppositions, although it is not perfectly satisfactory.

The Importance of Such Cases.—The importance of this case and of others like it, is that the determination of the particular center was made with such exceeding nicety, and its strength in the argument is that such a fine determination would have been impossible if the theory of localization had not been true.

Extirpation Experiments.—The third line of evidence is that which is derived from extirpation experiments. These experiments have been made upon various animals, principally dogs. The skull of a dog is opened, and some portion of the cortical surface is removed. The dog recovers from the operation, and then he is observed in order to discover what mental functions have been lost. If the portion of the cortex that has been removed constitutes the center for sight, the dog will be blind; if for hearing, he will be deaf, although the eye and the ear will be in as good condition as they were before. This method is best adapted to the discovery of the sense centers, which the study of the monkeys' brains by the method of electrical stimulation is not adapted to do, although the extirpation method may be employed satisfactorily to locate the motor centers.

Aphasia.—The fourth line of evidence is that derived from certain forms of disease called aphasia. Aphasia is a disease characterized by an inability to speak certain words, or classes of words, or any words. The meaning may be understood, and the person may be able to write

the words. There may be no paralysis of the vocal organs, but the patient loses the ability to speak certain words. In some cases it is the ability to write the words that is lost, while they may be spoken and understood. It is then called agraphia. Again it appears to be an inability to hear or to understand any of the words. This is sometimes called amnesia.

The Speech Center.—In all cases of aphasia, when there is an opportunity to make an examination, there is found to be a diseased condition of the brain in the region known as the speech center near the lower end of the fissure of Rolando, in the left hemisphere. This fact that the diseased portion is in the left hemisphere is probably associated with the fact that nearly all persons are right handed.

Localization Demonstrated.—Putting together the evidence derived from these four lines of investigation, the truth of the doctrine of localization seems to be placed beyond dispute. We shall see, however, that there are many modifications that must be made, and that there is a very true sense in which we may say that the whole brain is concerned in every mental operation.

The Motor Area.—Let us now discuss what has been learned about the location of different centers in the brain. The motor area has been determined with a great deal of accuracy, and lies along both sides of the fissure of Rolando. The centers from which start the impulses that move the legs are situated near the top of the fissure.

Along the middle course, lie the centers for the arms, while those for the head and face lie near its lower extremity.

The Sight Center, Hearing, Taste and Smell.—The sight center lies in the posterior portion of the cortical area, in the occipital lobe. Whenever a person sees anything, a nervous impulse is transmitted through some combination of cells in this region. Just below the fissure of Sylvius, in the temporal lobe, in what is known as Wernicke's convolution, is the area for hearing. When-

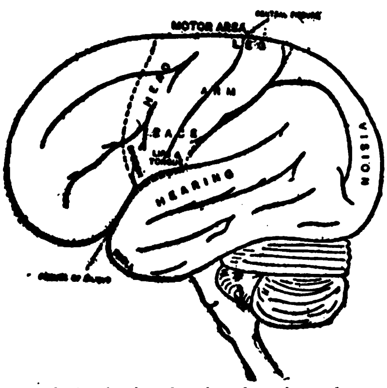


Fig. 5—Diagram of the brain showing location of motor centers, speech centers, centers for hearing, sight and smell.

ever a person hears anything, a nervous impulse is transmitted through some combination of cells in this area. In the lower portion of the temporal lobe, farthest away from the fissure of Sylvius, is the center for taste and smell. The difficulties of locating this area are much greater than in case of sight and hearing, and the determination consequently cannot be accepted with the same degree of confidence. However, we may believe that the

determination has been accurately made until the conclusion has been shown to be wrong.

The Speech Center.—Just above the fissure of Sylvius, at the lower end of the fissure of Rolando, in close proximity to the motor area, if indeed not a part of it, is the speech center. This speech center is functional only on one side of the brain, which in nearly all cases is the left side.

Other Sense Centers.—These centers are the only ones in whose determination we can place much confidence. Other centers have been determined, but the evidence for their location is not very conclusive. Just behind the motor area, and probably overlapping it, is believed to lie the center for the sensation of touch. Probably also in the same area, or close to it, lies the center for temperature. From the conclusions reached in the attempt to locate the different centers, we may confidently believe that every sensation has its own center, although it may be a long time before the definite location of some of them will be discovered.

Association Areas.—When we have subtracted from the cortical surface all the portions whose functions we know, such as the sight center, the hearing center and the motor center, there are large areas for which no function has been definitely determined. Between the sight center and the center for touch and movement is a large unexplored area. In the frontal lobe is another. These are sometimes called association centers, and it is believed that nervous impulses from different sense centers

enter into combination here. Also some have assumed that these areas are thought portions of the brain, and Haeckel has called them the phronema, or thought portion of the brain.

Association Areas Problematical.—All such determinations are extremely problematical and cannot be accepted as definitely established. It can be shown that there are no higher processes of thought than those which accompany the transmission of different nervous impulses from one portion of the brain to another. Hence, while we may call these association areas, we should be careful not to imply that we really know anything at all about their especial functions. It would be just as well to call them unexplored areas.

DEFINITIONS

Localization of Function—A theory that every portion of the brain performs its own function, which is different from that performed by every other portion.

Brain Center—A portion of the cortex that is concerned in one function. A particular combination of brain cells traversed by a single impulse.

Phrenology—A pseudo-science which professes to determine character by an examination of the bumps on the skull.

Motor Area—That portion of the cortex from which impulses proceed to the muscles, producing movement.

Sight Center—That portion of the cortex in which are located the combinations of cells traversed by an impulse when the sensation of sight is experienced.

Association Area—One of the several areas of the cortex not included in the sense centers, in which some believe the different sensation impulses meet and mingle.

CHAPTER III

THE NERVOUS SYSTEM.

It might be said that the need for a visible image of the mind is actually met by nature in the method of function of the nervous system.—*Hoffding, Psychology, p. 50.*

The modern study of the functions of the mind has shown beyond all question that these are dependent upon the functions of the body, especially of the nervous system.—*Metchnikoff, Nature of Man, p. 159.*

We must content ourselves at present by considering it highly probable that every process of thought has a physical aspect, even though we are very far as yet from being able to trace it out.—*Karl Pearson, Grammar of Science, p. 47.*

In the absence of a nervous system we have no right to look for its product, consciousness.—*Huxley, Hume, p. 126.*

If, on the other hand, we make up our minds to consider nervous processes as the actual condition of centrally excited sensations, we have the advantage of being able to explain all the facts, in principle at least, without putting pressure upon them, or shifting our point of view. We also reap the benefit of basing theory upon a universal law of nervous structure and function which obtains, whether or not there are psychical phenomena to accompany the excitation. It cannot be charged against such explanation that it is either arbitrary or hypothetical.—*Kulpe, Psychology, p. 219.*

Spinal Cord and Medulla.—The spinal cord is a continuation of the medulla; or perhaps it is easier to think of the medulla as being that portion of the spinal cord which lies within the skull. This statement will help us to think of the relation of the two organs to each other, although it is not strictly accurate. The spinal cord is from fifteen to eighteen inches long, and lies in a canal of bone formed by the backward extending processes of the

several vertebrae that make up the spinal column. The spinal cord does not run through the vertebrae, but lies behind the centra, which we may consider to be the vertebrae themselves, and the canal in which it lies is formed by processes arising from the centra.

Two Enlargements.—If we examine the spinal cord after having removed it from the cavity in which it lies, we shall find two enlargements along its length. One is the cervical enlargement, about on a level with the shoulders and neck, and is the portion of the cord from which proceed the nerves that go to the arms and shoulders. The other is the lumbar enlargement, and is the portion from which start the nerves that run to the legs.

Anterior and Posterior Fissures.—The spinal cord is divided into two parts by two longitudinal grooves, or fissures: the anterior fissure, running along the front, or ventral side of the cord; and the posterior, along the back, or dorsal side. The two fissures divide the cord into a right and left half, which are connected by a portion of the nervous matter extending from right to left sides. The anterior fissure is broader and not so deep, while the posterior fissure is narrower and deeper than the anterior.

Arrangement of the Gray Matter.—The spinal cord is composed of gray and white matter, as is the cerebrum; but in the cerebrum the gray matter is on the outside, while in the spinal cord it is within. If we look at a cross section of the spinal cord, we shall see that the gray matter is arranged in a figure somewhat resembling

the shape of the capital letter H. The extremities of the vertical bars of the H are called the horns of the gray matter, or cornua. The front horns are more rounded, blunt, and do not come so near to the surface of the cord as do the posterior horns.

The Spinal Nerves.—In the skull are twelve pairs of cranial nerves, some of which are exclusively sensory, such as the optic and olfactory nerves. The head and

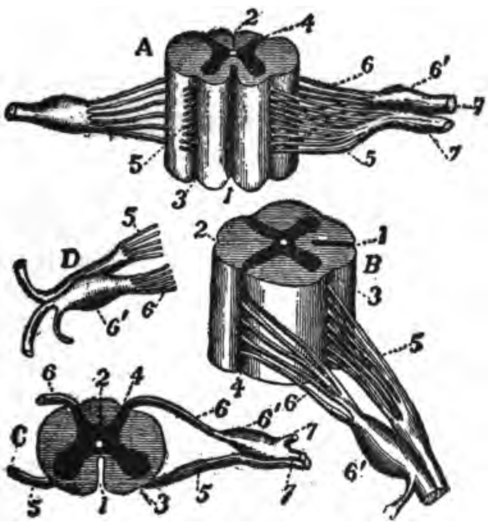


Fig. 6—Sections of the spinal cord showing the arrangement of the gray matter, the cornua, origin of the spinal nerves, nerve roots and sensory ganglia.

face muscles are supplied with nerves that originate in the medulla. From the spinal cord start out thirty-one pairs of spinal nerves, which run to all parts of the body below the head. Each pair consists of a right and left nerve, leaving the cord at the same level.

The Nerve Roots.—Each spinal nerve leaves the cord by two roots, an anterior and a posterior root. The anterior root originates in the anterior horn of the gray matter, while the posterior root originates in the posterior horn. The anterior root contains fibers that go to the muscles, and an impulse passing along the fibers of this root causes the muscles to contract, producing motion. On account of the movement produced by it, it is called the motor root. Since it starts from the anterior horn, it is called the anterior root; and since the impulses it conveys run outward, from the cord, it is called the efferent root. Anterior, motor, efferent are three names applied to the same root, although each word indicates a different aspect of the root.

Difference of the Two Roots.—The posterior root sends its fibers mostly to the sense organs in the skin, or on the outside, periphery, of the body. Since it starts from the posterior horn, it is called the posterior root. Since the impulses it conveys run inward, from the periphery of the body to the spinal cord, it is called afferent; and since the impulses it conveys accompany sensations, it is called the sensory root. Posterior, sensory, afferent are three terms all applied to the same root.

The Sensory Ganglion.—The roots of the nerves do not leave the cord as a single trunk, but each root consists of several or many fibers, or small nerves. The several fibers and small nerves coalesce into a single trunk, and the two roots combine to form a single nerve. On the posterior root, close to the point of its junction

with the anterior, is a small knot of nervous matter, called the sensory ganglion. No such structure occurs on the anterior root. After the nerve has been formed by the junction of the two roots, it begins to send off branches to the various parts of the body, each branch dividing and subdividing until the nerve is distributed to the entire region to which it goes.

Effect of Severing the Roots.—If the sensory is cut without interfering with the motor root, all sensation will be destroyed in that part of the skin to which the sensory fibers are distributed, without impairing the ability to

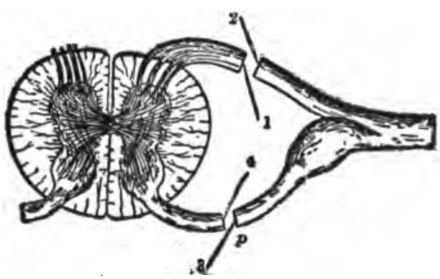


Fig. 7—Spinal cord and nerve roots. Effect of cutting the roots separately.

move the muscles with which the motor root is connected. Similarly, if the anterior root is cut, the sensibility will be retained in the skin to which the sensory fibers are distributed, but all power to move the muscles with which the motor fibers are connected will be lost.

The Nerve.—The nerve itself looks like a white cord; but instead of being a single cord it is a collection, or aggregation, of very fine threads of nervous matter which are called fibers. Each fiber is continuous throughout its

whole length, which in some cases may be as much as two or three feet, although much the larger number of fibers are greatly less. The fibers themselves do not branch, but the different fibers that constitute the nerve separate, so causing the nerve to branch.

The Nerve Fiber.—The essential part of the nerve fiber is the axis cylinder, consisting of semi-fluid protoplasm, and which constitutes the conductor of the impulse. The axis cylinder is surrounded by a white membrane called the medullary sheath, which disappears near each extremity of the fiber. Its function is not positively known, but the best hypothesis about it is that it serves as a kind of insulator, preventing the nervous impulse from leaving the axis cylinder.

Neurilemma.—Outside of the medullary sheath is a thin membrame called the neurilemma. The entire number of fibers in a nerve are held together by connective tissue, and surrounded by a nerve sheath, or perineurum.

Transmission in a Fiber.—A nerve fiber will transmit an impulse in either direction. The reason why we speak of afferent and efferent fibers is because the impulses that the sensory fibers transmit are started in the ends of fibers farthest from the spinal cord, while the motor impulses originate in the cortex, or in the gray matter of the cord.

Neurons.—The essential elements of the brain cortex consist of ganglion cells, or neurons. The principal part of a neuron is the cell body, inside of which is a nucleus,

and enclosed in that is a smaller body called the nucleolus. The nucleus constitutes the essential part of the

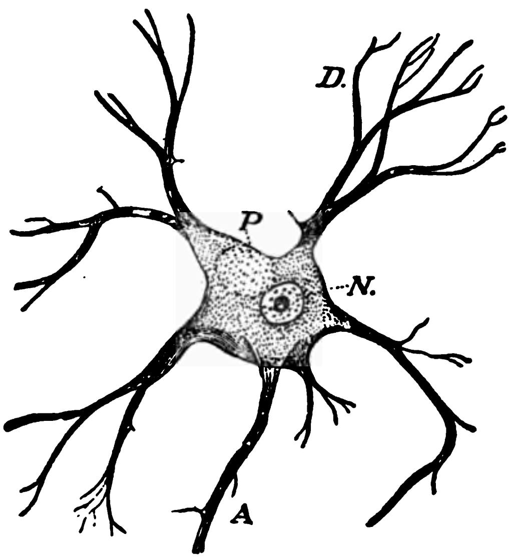


Fig. 8—A neuron showing cell body, dendrites, axon. A is the axon, D are dendrites.

cell, and when the cell becomes fatigued it is the nucleus that changes its shape and becomes smaller.

The Dendrites. — From the cell body proceed branches, or roots, called dendrites. These dendrites branch freely, at acute angles, like the branches of a tree. The word dendrite is derived from a word that means tree. They are not separated by partitions from the cell body, but constitute a portion of the cell mass. Some cells have dendrites that are much longer and more

numerous than other cells, and the difference between a

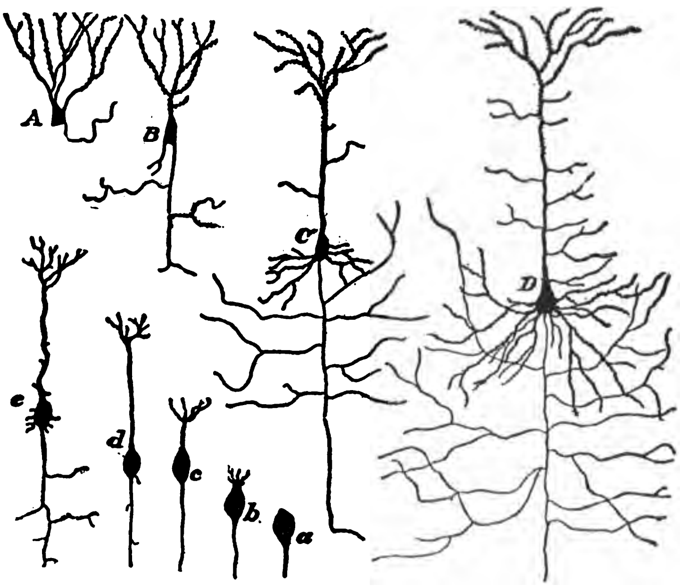


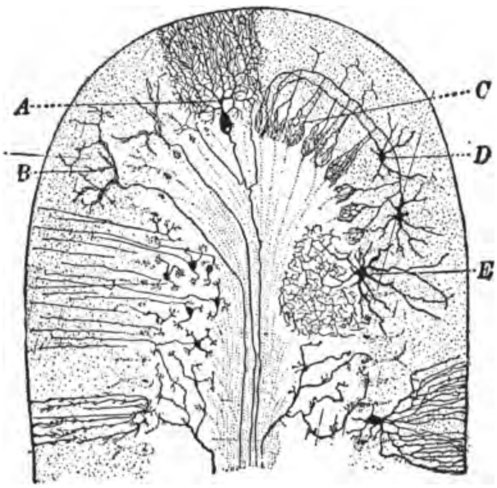
Fig. 9—Different kinds of neurons. A, from the brain of a frog; B, lizard; C, rat; D, man. a, b, c, d, e represent different stages in the development of a single neuron.

developed and an undeveloped cell is seen most clearly in the number and extent of the dendrites.

The Axon.—One branch of the cell differs considerably from the other branches. It does not branch so freely, and the branches that it does send off proceed from it at right angles. This branch is called the axon, and its continuation becomes a nerve fiber. Every nerve fiber is the axon of some cell. The name axon is intended to mean the same thing as axis cylinder.

The Neuron.—The entire cell structure, with the cell body, nucleus, nucleolus, dendrites and axon is called a neuron. Every neuron is independent of every other neuron, so far as physical contact is concerned. In only a few cases is there any direct physical contact between any neuron or its branches and those of any other neuron.

Neuroglia.—In one layer of the cerebellum are found some cells of a bewildering degree of complexity. These are called the Purkinje cells, and their function has



CELLS IN THE CEREBELLUM

Fig. 10—Different kind of neurons found in the cerebellum.

not been satisfactorily determined. Surrounding the cells, and constituting a kind of packing material, is a substance called neuroglia. Besides holding the cells in

place as packing material, the neuroglia furnishes an insulation which serves to prevent a nervous impulse passing from one cell over into another except under proper conditions. While the neuroglia is nervous material, its function is subsidiary to that of the neurons.

The Gray Matter.—The neurons constitute the essential part of the gray matter. It is their presence that makes it gray. The white matter is composed principally of fibers, and it is the fibers that make it white. The white appearance is given to it by the medullary sheath, for if it were only the axis cylinder that showed, it would in all probability present the same gray appearance that is shown by the rest of the neuron.

Difference Between Fibers and Cells.—The fibers transmit impulses only. The neurons, or cell bodies, not only transmit impulses, but liberate energy and originate impulses. All the nervous energy that is liberated comes from the neurons, or ganglion cells. There is little or no nervous energy produced in the white substance of the brain. There is much oxidation of tissue in the ganglion cells of the gray matter, but little oxidation occurs in the fibrous white matter. It follows also from this that there is little fatigue of the nerve, while the ganglion cell becomes easily fatigued.

Number of Neurons.—The number of ganglion cells is very great. Seven hundred million is a low estimate, while other estimates run from ninety-two hundred mil-

lion to thirteen billion. The difficulty in counting them is

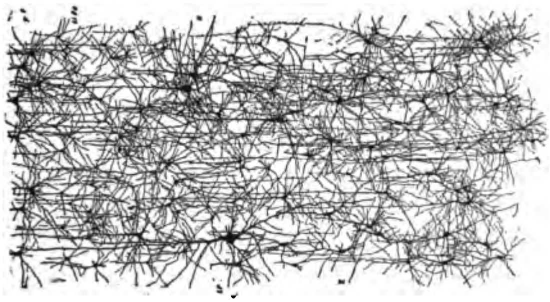


Fig. 11—General appearance of the neurons with their dendrites as they are embedded in neuroglia.

so great that it is not strange that estimates vary widely.

Direction of the Impulse.—It is believed that a nervous impulse always enters a neuron by way of a dendrite, and leaves it over the axon. It is believed that the impulse will not travel in the other direction. The statement of this fact as known as the Bell-Magendie law, or the law of the forward conduction of the impulse.

The Bell-Magendie Law.—It may be questioned whether the law is universally true. If it is true, it appears that the blocking of the backward flowing impulse does not occur in the cell body nor in the axis cylinder, which are perfectly indifferent structures, so far as conduction is concerned. But the blocking of the impulse occurs in some way at the point where the transmission of the impulse from one cell to another occurs, which is the point where the axon of one cell and the dendrite of the other most nearly approach each other. This point of nearest approach is called the synapse, and is the point

at which exactly occurs the process which is the concomitant of the mental process. It is here that the physiological change occurs that invariably accompanies the mental process.

The ganglion cells, or neurons, are the portions of the nervous system most immediately concerned in mental processes, and the physiological changes that accompany mental processes always are associated with the ganglion cells. Thus we have traced the mental processes to their association successively with the nervous system, the brain, cerebrum, cortex, gray matter, ganglion cells, and lastly we locate it definitely at the synapse.

DEFINITIONS

Neuron—The ganglion cell with all of its branches and appendages.

Dendrite—One of the branches of the neuron, or ganglion cell.

Axon—That branch of the neuron which is continued as the axis cylinder of a nerve fiber.

Spinal Cord—That portion of the nervous system outside of the skull, which is enclosed in a bony cavity formed by the vertebral processes.

Cornua—The horns of the gray matter in the spinal cord.

Medullary Sheath—The white covering of a nerve fiber.

Axis Cylinder—The central portion of a nerve fiber, which is the conductor of the nervous impulse.

Sensory Root—The posterior root of a spinal nerve leading from a sense organ.

Motor Root—The anterior root of a spinal nerve, leading to a muscle.

Sensory Ganglion—The knot of nervous matter on the sensory root.

Neurilemma—The covering of a nerve fiber outside of the medullary sheath.

Perineurum — The outside covering of the entire nerve.

Synapse—The point at which the dendrite of one cell and the axon of another most nearly approach each other. The point at which the nervous impulse passes from one cell over to another.

Bell-Magendie Law—A statement of the fact that a nervous impulse will pass in one direction only, and not in the opposite direction, along a nervous arc, or from one cell to the other. Called also the Law of Forward Conduction.

CHAPTER IV

THE NATURE OF THE NERVOUS IMPULSE.

The problem, How does the Impulse find its way from A to B, is the crucial problem for physiological psychology.—*McDougall, Physiological Psychology, p. 126.*

Reverting then, to the common hypothesis of a "nervous fluid" which moves in nerve "currents," admitting that though the molecular motion which works nervous effects is not a fluid, and its transfer is not a current,—they may be conveniently dealt with as though they were.—*Spencer, Psychology, Vol. I, p. 586.*

Experience shows that nerve force is generated and set free wherever the cerebro-spinal system is excited.—*Darwin, Exprssion of the Emotions, p. 349.*

According to this idea, living proteid does not need to have a constant molecular weight. It is a huge molecule and undergoing constant and never ending formation, and constant decomposition, and probably behaves toward the usual chemical molecules as the sun behaves toward small meteors. *Baldwin's Dictionary, Volume II, p. 9. Art. Living Matter.*

We may conclude from these experiments that the movement process of stimulation is relatively slow; for the frog nerve at ordinary temperatures it averages 26, for the nerves of warm-blooded animals at normal body temperature, 32 meters in one second. And second, that it consists in all probability, not in a simple transmission and propagation of the external stimulus movement, but in a chain of movement processes released from one point to another in the nerve itself.—*Wundt, Physiological Psychology, p. 69.*

The Dualistic Theory.—In our preceding chapters we have made the assumption that in some way mental processes are associated with nervous structure and with physiological changes. The nature of this connection we are unable to determine. Some persons, whom we may

call dualists, believe that mind and body, mental processes and physical changes, are completely distinct from each other. They believe that the mind is one thing and the body is another. While the two things may be associated with each other, neither is absolutely essential to the other's existence. In fact, of the two, the body is of considerably less importance, the mind merely using the body as an instrument to produce changes in the material objects of the external world. The only physical or physiological changes that accompany mental processes are those which the mind produces in the body by its own self-activity.

The Monistic Theory.—On the other hand, there are persons whom we may call monists, who believe that mind and body are not two separate things, but merely different aspects of the same thing. Mind, or mental processes, is nothing more than a function of the body, depending upon and produced by the physiological activity of the organs of the body, particularly the brain.

Parallelism, or Correspondence.—Between these two opposing views we are unable to decide. Neither can demonstrate to the satisfaction of the other the truth of his own contention. Hence it is necessary for us to adopt some kind of a working platform upon which both dualists and monists may stand. Such a platform we may find in the doctrine of parallelism, or correspondence.

What the Doctrine Asserts.—The doctrine of parallelism, or correspondence, asserts that for every mental

process there is a corresponding physiological change. It will not do to turn the statement around and say that for every physiological change there is a corresponding mental process. There is a great deal of difference between a house dog and a dog house. There are many physiological changes that are not accompanied by mental processes. But when we experience a mental process, we may feel quite sure that some physiological change is occuring, and it is the same physiological change that accompanies the same mental process under all conditions. Hence when we have found the physiological change occurring, we may be confident that a particular mental action is in progress; and while we do not know the nature of the connection, it assists us in understanding the mental process to picture its concomitant in physiological terms.

The Nature of the Correspondence.—The doctrine of parallelism makes no assertion concerning the nature of the connection between the mental process and the physiological change that accompanies it. The dualist will assert that the mental process is the cause of the physiological change, and will agree to the doctrine. The monist will assert that the physiological change causes the mental process, and also agree to the statement of the doctrine. But the doctrine itself implies neither, and may even assert that the parallelism is a purely accidental circumstance.

The Nervous Impulse.—The physiological change that accompanies the mental process, and which we may

call its concomitant, always takes the form of the transmission of a nervous impulse through a nervous arc. A nervous arc in its simplest form consists of an afferent nerve, a ganglion cell, another ganglion cell, and an efferent nerve. There must be at least two neurons involed in the arc, and the number of cells in almost any nervous arc that is traversed when we experience a mental process is doubtless very large. Perhaps we shall have to reckon the number in hundreds of thousands for the arcs that are traversed when we experience most of our mental processes.

Chemical Composition of Nerve Tissue.—In order to understand the nature of the nervous impulse, it will be necessary to know as much as we can about the structure of the nervous tissue. Brain tissue is composed principally of four elements, carbon, nitrogen, hydrogen and oxygen. These are represented by the letters C. N. H. O. Besides these, several other elements exist in small quantities; phosphorus, sulphur, iron, calcium, sodium, potassium and possibly a few others. But these latter elements are insignificant in quantity, although perhaps the nerve tissue could not be nervous without them.

The enumeration, however, of the chemical elements, gives us no notion of the nature of the nervous substance. The atoms and molecules of these elements may be combined in hundreds of different ways to produce as many different kinds of substances.

Nerve Substances.—We know that many different kinds of substances exist in the brain, but the difficulties

of analyzing living tissue are almost insuperable. As soon as we undertake to manipulate living tissue according to the methods of chemical analysis, the tissue is no longer living, and changes to a substance of an entirely different nature. Some of the substances that have been discovered in the brain are called cerebrin, lecithin, cholesterin, neurokeratin and protagon. It must not be understood that the whole brain is composed of these substances, for when all of these substances have been subtracted from the brain, a considerable portion is left, which is doubtless composed of many kinds of substances different from any of those named.

Complexity of Molecules.—These substances are very complex. By this it is meant that the molecule of each of these five substances is composed of a great many atoms. A molecule that is composed of a small number of atoms is simple, while one that is composed of a great many is complex. Common salt has a very simple molecule, composed of one atom of sodium and one atom of chlorine. Water has three atoms in the molecule, two of hydrogen and one of oxygen. Ammonia has four atoms in the molecule, three of hydrogen and one of nitrogen. Sulfuric acid has a rather more complex molecule, of seven atoms, two of hydrogen, one of sulphur and four of oxygen.

Organic Substances.—Ordinary sugar is produced in the growth of sugar cane, or sugar beets, and has a molecule that is much more complex. Its molecule contains 45 atoms; 12 of carbon, 22 of hydrogen, 11 of oxygen.

There are two very important observations to make in this connection; one is that such complex molecules as those of sugar are produced only by living beings, and are therefore called organic substances. The other is that substances which are composed of such complex molecules are easily changed, or decomposed. Decay is one of the changes to which substances having such complex molecules are susceptible. If we dissolve salt in water, the solution will not spoil, nor change nor decay. The salt will still remain salt. But if we make a weak solution of sugar, the sugar will change first to alcohol and later to vinegar, if conditions are at all favorable.

Characteristics of Nitrogen.—Especially will these changes, including the change of decay, occur, if nitrogen is one of the elements which constitute the molecule. Nitrogen is an inert element. It can scarcely be made to combine with anything else. We may pass a draft of air through the furnace, and all the oxygen will combine with the glowing coal. But the nitrogen, which comprises about four-fifths of the air forced through the furnace, will pass over the white hot coal and not enter into combination with it under the most favorable conditions.

Nitrogen in Explosives.—There are compounds of nitrogen found in the earth, such as potassium nitrate and sodium nitrate, which are known as saltpeter, and we may take advantage of this laziness of nitrogen to make it useful. Nitrogen, when it is in combination, will let loose of the things with which it is combined very readily. So we make gunpowder, using a compound of nitro-

gen, and at the slightest excuse, the nitrogen lets go of the thing with which it is combined, and we have an explosion, which is merely the liberation of enormous quantities of nitrogen gas. It is nitrogen that constitutes the explosive force of nitro-glycerin and dynamite. In the same way, nitrogen readily lets go of any substance with which it may be combined in a nerve molecule, and we have a change, which in consequence of the similar cause of the change in gunpowder, is sometimes called an explosion of a nerve cell.

Nitrogen in Organic Substances.—Nitrogen forms a part of very many of the organic substances which constitute the body of an animal or plant, and which are produced by them. Hence we find that very many organic substances readily undergo changes, one of which is decay, or decomposition, although there are many other changes that organic substances undergo in the body of any animal or plant while it is still alive. Organic substances that do not contain nitrogen are not nearly so susceptible to decay as are those into whose composition it enters. Fats and oils do not contain nitrogen, and they do not readily decay. Lard, turpentine and linseed oil, although they are organic substances, and have complex molecules, are scarcely susceptible to decay.

Molecular Constitution of Nerve Substances.—Nearly all substances which make up the nervous tissue contain nitrogen, have very complex molecules, and are consequently easily changed in a great many ways. The substance cholesterin is believed to have a molecule com-

posed of 74 atoms, which is almost twice as many as the molecule of sugar contains. Protagon is a substance that is believed to have a great many atoms in the molecule. It is difficult to determine accurately its molecular formula, but it is believed that each molecule contains 509 atoms; 160 of carbon, 308 of hydrogen, five of nitrogen, one of phosphorus and 38 of oxygen. A molecule as complex as this, especially if it contains nitrogen atoms, must be so unstable that it is almost constantly in a condition of change, and the amount of force necessary to bring about a change in it must be almost inconceivably small.

Nerve Molecules Easily Changed.—We may not be perfectly assured that we know exactly the molecular composition of protagon; and it may be true, as has been suspected, that protagon is not a simple substance, but a mixture of two or three other substances. But the truth that we learn from all of our investigations, and our attempts to determine the chemical constitution of the brain, is that the nerve subsances are composed of very complex molecules, and that they are exceedingly easy to become changed. Decay in a dead animal always begins with the brain.

Isomeric Change.—The change that a molecule of nervous substance undergoes in a living body is usually some kind of isomeric change. In an isomeric change, the number and kind of atoms in the molecule remains the same, but they take on a different arrangement, and maintain different relations to each other. If we think of the atoms at first having a definite arrangement in the

molecule, and then under the influence of some other circumstance rearranging themselves without leaving the molecule or adding another atom to it, we shall have an idea of an isomeric change.

A Chemical Change.—The ordinary chemical change is one in which the number and kinds of atoms that make up the molecule after the change are different from those which constituted it before. Usually in a chemical change some of the atoms in a molecule leave it, and their places are taken by other atoms from other molecules; but it is usually the case that the atoms which take the places of those that are liberated from the molecule are different both in number and kind from those whose places the usurp.

Illustration of Water.—Water exists as water, ice and steam. The chemical formula is the same in each, and there is no change in the molecule in changing from one state to the other. This will assist us in understanding the difference that may exist in substances without any change in the constitution of the molecule, although in this case it is a change in physical state, not an isomeric change in the molecule. It is an illustration of an isomeric change, not an example.

Of Forms of Carbon.—Carbon exists as pure carbon in three forms: lampblack, such as appears in the chimney of a smoky lamp; graphite, of which the lead in a leadpencil is made, and diamond. Lampblack and diamond will burn, but crucibles in which metals may be

melted are made from graphite. If we could observe lampblack, graphite and diamond changing from one to the other, we should have an example of an isomeric change.

Among organic substances there are many examples of isomeric changes. The chemical formulae of the substances remain the same, but in some way the atoms rearrange themselves and the substance takes on new and totally different properties.

Nervous Impulse an Isomeric Change.—The change that occurs in nervous tissue when a nervous impulse traverses it, must be some kind of an isomeric change, as was pointed out by Herbert Spencer nearly sixty years ago. In a molecule as complex as protagon, there must be opportunities for a hundred different changes, transforming it into a hundred different substances, and yet the molecule in each substance consisting of exactly the same atoms that are found in any of the ninety-nine other substances.

Colloidal and Crystalloidal.—Nerve tissue in its ordinary form is a colloidal substance. When it undergoes the change that occurs in the transmission of a nervous impulse, it changes to a crystalloidal form. Colloidal and crystalloidal forms of matter differ in at least two respects; the name crystalloidal is applied in consequence of the fact that when it solidifies, the form of matter to which it is applied crystallizes, or takes on the shape of crystals. Water is a good example of a crystalloidal form of matter. Water crystals are seen in the snowflakes,

the frost crystals on a window pane, or on the surface of a vessel of water when it freezes.

A colloidal form of matter will not crystallize when it becomes solid. The white of an egg is a good example. This difference is of more significance than it at first appears to be.

Osmosis.—The most important difference between colloid and crystalloid is the fact that in solution a crystalloid will pass readily through a membrane, while a colloid will not. An easy experiment will nicely illustrate the matter. If the shell of an egg be broken at the large end without rupturing the lining membrane, and the egg be placed so that the broken end is in the water, the water will pass readily through the membrane into the egg, but the egg material, being colloidal, will not pass readily outward into the water. Pressure is therefore exerted upon the inside of the egg, and if the shell is broken at the top, some of the contents will be forced outward at that place. By sealing a glass tube to the shell at the top, the pressure may be measured by the distance up the tube to which the contents are forced.

Change from a Colloid to a Crystalloid.—The nervous matter in its ordinary state is a colloid. The crystalloidal form is the one that is necessary to permit any portion of it to pass through a membrane, and it may be a necessary condition for the influencing of a tissue by nervous force, that the nervous matter must be in a crystalloidal form. In order to make a muscle contract, the molecules of the nerve endings, where it enters the muscle, must have the crystalloidal form.

Energy Liberated in the Change.—When the nervous molecule does change, it must change back again in order to repeat the process. This change from a colloidal form to a crystalloidal and back again occurs from 10 to 20 times in a second. This means that a good deal of energy is expended in making so rapid changes, and this expenditure of energy is indicated in several ways. There is considerable amount of tissue oxidized, and a consequently large amount of waste matter to be excreted in the form of carbon dioxide and other waste products. Many years ago it was proposed to use the amount of phosphorus excreted as a measure of the amount of nervous energy expended, and those great scientific authorities, the newspaper men, widely advertised the fact that thought depended upon phosphorus, and that a diet rich in phosphorus was necessary to the production of thought. That is all there is to the phosphorus theory of thought, or a fish diet as brain food.

Loss of Tissue.—Not only can we detect a great oxidation of tissue in the brain cells, in association with nervous processes, but an actual change in the shape and size of the cell has been observed. This means that some of the substance of the cell escapes from its boundaries, and whether any of it goes off directly as a result of its becoming a crystalline form of matter, and by so doing affects other nerve cells and muscles and glands with which the nerve is connected, or whether the loss may be accounted for by the waste that is excreted, would be a difficult matter to determine.

What an Impulse Is.—But a mere change in condition does not constitute a nervous impulse. An impulse implies a change in successive portions of a conducting substance. In a nerve, the impulse, or current, consists of a change in successive molecules of the axis cylinder. One molecule changes, and as a result of this change, the molecule next to it changes, and this causes a third one to change, and so on until the last molecule in the nervous arc has been changed. The process is well illustrated by a row of bricks set up on end, and not farther apart than the length of one brick. When the first brick in the row is toppled over, it strikes the second in the row, knocking it down, and the fall of the second brings about the fall of the third, and so on until the last brick in the row is knocked over.

Fatigue of Nerve Molecules.—The nerve molecules are like the bricks in the row, except that when the nerve molecules have been changed, or knocked down, each one will get right up and be ready to be knocked over again. The process of getting up and being knocked down in the case of the nerve molecules goes on rather rapidly; from 10 to 20 times in a second. It is rather a vigorous process to be knocked down and get up so rapidly, so that the cells soon become fatigued and must rest for a time in order to recuperate.

Rate of Transmission.—It is evident from the illustration that the molecules do not all change at the same instant. One molecule must change before the second one can change. It is this succession in change that

constitutes the impulse. It is evident, also, that the process takes some time. There is a measurable interval between the change in the first molecule of a nerve and the last molecule that is changed. We use the expression, sometimes, "As quick as thought." If by that expression we mean as quick as the nervous impulse travels, we do not mean any very great rate of speed. Sound travels at the rate of about 1,100 feet in a second; light moves at about 186,000 miles, eight times around the earth, in a second; electricity in a good conductor will go about as fast; but the nervous impulse lazies along at about 100 feet in a second, in a nerve, while in a brain center it goes not more than from one-tenth to one-twentieth as fast. If a man were 400 feet high, and should put his bare foot on a live coal, or a piece of red hot iron, it would be four seconds before he would feel any pain, or know that his foot were burning. Then he would start an impulse back to remove the foot from the hot iron; but as it would require four seconds for the impulse to reach the foot, the burning would continue eight seconds before the foot could be removed. We ought to be glad that we are not 400 feet high.

Transfer of Atoms.—It is possible that we may image the process that goes on in the molecule while a nervous impulse is in progress in such a way as to make its comprehension easier. We may invent some kind of an hypothesis to account for the changes that occur. Let us represent a molecule of the axis cylinder by a group of atoms having a triangular arrangement with the apex at the left. Let us suppose this arrangement to represent

the colloidal state of the molecule. Some force impressed upon the molecule A changes its shape in such a way that one atom leaves A, flies off to molecule B, striking

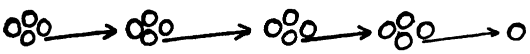


Fig. 12—Diagram showing the molecular changes in a nervous impulse. The arrow shows the position of the atom in the molecule from which it is driven, and the position it assumes in the molecule to which it goes.

it, changing its shape to trangular with the apex at the right, and driving off an atom to molecule C, and so on. The change in shape will correspond to the change from colloid to crystalloid. The molecule will contain the same number and kinds of atoms that it did before, but the atoms will have a different arrangement, and indeed they will not be the identical atoms that previously composed the molecule. In this respect our definition of an isomeric change will need modification.

Possibly of Corpuscles.—But we do not need to limit ourselves to the supposition that it is the atom that is transferred from one molecule to the next. Formerly it was believed that the atom was a hard, incompressible, homogeneous thing, incapable of modification, and not composed of smaller elements. Now it is believed that every atom is composed of smaller parts, called corpuscles, or electrons, varying according to the kind of atom, and its atomic weight, from 1,000 to 200,000 in each atom, and moving within the atomic space at rates varying from 50,000 to 150,000 miles in a second. This gives each corpuscle, notwithstanding its small size, considerable force.

Instead, then, of its being an atom that is shifted from one molecule to another, thus making the nervous impulse, it is possible that it is the corpuscles of various atoms that are thus shifted. However, the shifting of atoms is easier for us to understand, and so long as it fills every requirement, we may adopt it as an hypothesis concerning the real change that constitutes the nervous impulse.

DEFINITIONS

Nervous Impulse—The change that occurs in successive molecules of a nervous arc.

Nervous arc—The nervous pathway over which a nervous impulse is transmitted.

Molecule—The smallest division of a substance that can be made and still manifest the properties of that substance.

Atom—One of the constituent parts of a molecule.

Corpuscle—One of the constituent parts of an atom.

Isomeric Change—A change in the arrangement of the atoms in a molecule without any change in the number or kinds of atoms. The molecule may have different properties after the change from what it had before.

Colloidal—A form of matter that does not crystallize upon solidification.

Crystalloidal—A form of matter that does crystallize when it becomes solid.

CHAPTER V

THE SENSE OF SIGHT.

The human retina, he remarks—(Max Schulte)—is formed as it were of two associated retinae: that of the cones and that of the rods. The former yield the sensation of light and darkness, and further, all the color sensations. The second supplies only the sensations of light and darkness.—*Morat, Physiology of the Nervous System, p. 261.*

The rods are found almost exclusively in the retinae of nocturnal animals (owls, bats, hedgehogs). In most birds the cones predominate, or are alone present.—*Morat, p. 561.*

A microscopic examination shows that this coloring matter which has been termed visual purple is entirely confined to the outer portion of the retinal rods, and does not occur at all in the cones.—*American Text Book of Physiology, Volume II, p. 250.*

It is perhaps true that the rods act only when the light is dim, and give no sensations at all for green.—*Thorndike, Psychology, p. 27.*

Sense Organ a Machine.—A nervous impulse is started by force from the outside, acting upon some sense organ especially adapted to the kind of force employed. The eye is an organ especially adapted to the force of light, and is the machine by which light establishes an impulse. We shall study it as an apparatus by means of which a nervous impulse is established.

Coats of the Eye.—The eye is essentially a globe, although the axis from front to back is somewhat longer than that from side to side. It is covered by three coats,

the outer of which is the sclerotic, a dense, fibrous, inelastic membrane which holds the eye in shape. The

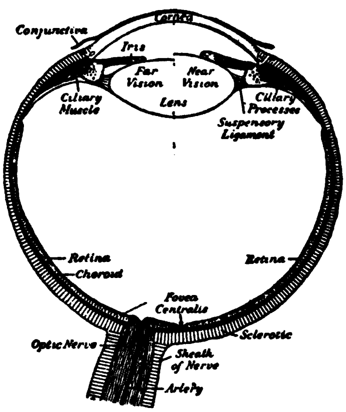


Fig. 13—Diagram showing parts of the eye.

sclerotic coat does not extend completely around the eyeball, but in front its place is taken by a membrane called the cornea, which is transparent and constitutes the front surface of the eye. The sclerotic coat may be seen as the white of the eye all around the cornea.

The Choroid and Iris.—The second coat of the eye is the choroid, which is displaced in front by the iris. The iris is a colored membrane, and it is the color of the iris by which the color of the eye is designated. In the middle of the iris is a hole called the pupil. While the pupil is not really a part of the eye, it is such a conspicuous mark that we may consider it as if it were. The pupil is always black, because we see it as the opening into a dark cavity, from the inside of which little or no light is reflected. The pupil changes its size to correspond to the amount

of light that enters it. When the amount of light available for seeing is small, the pupil enlarges so that as much as possible will enter. When the intensity of light is great, the pupil diminishes, thereby excluding an amount that might be detrimental to seeing.

The Change of Size in the Pupil.—The mechanism by which this change in size is brought about is found in two sets of muscles in the iris. One set runs from the edge of the pupil to the outer edge of the iris. These are the radial muscles, and when they contract they diminish the distance between the outer and inner edges of the iris, thus enlarging the pupil. The other set are the circular muscles, which run around the pupil. The effect of their contraction is to draw the edges of the pupil closer together, thus diminishing its size. These changes in the size of the pupil are involuntary and reflex. We can not will to make the pupil smaller or larger, but the stimulus to the muscle is found in the light itself, thus regulating the size of the pupil and the amount of light that enters it automatically.

How Observed.—These changes in the size of the pupil may be observed by every one in his own eye. If one stands in front of a mirror in a darkened room, holding a candle, lamp or other source of illumination behind him, the pupil will become enlarged. Then bringing the candle in front so that its light will fall upon the eye, the rapid contraction of the pupil can be witnessed in the mirror.

Variation in Different Eyes.—The pupil in the human eye is circular, but in the eye of the cat the radial muscles are so attached that the pupil closes into the shape of a vertical slit. In the eye of the owl the circular muscles are incapable of sufficiently closing the pupil, so that the owl is almost blinded by day in consequence.

Detrimental Effects of Reading While Facing the Light.—It will be seen from this description of the method by which the size of the pupil is controlled that there is a serious danger in trying to read when facing the light. The light entering the eye from the source of illumination stimulates the circular muscles to contract in order to shut it out. The small amount of light received from the page which we are trying to read, and which is turned away from the light, stimulates the radial muscles to enlarge the pupil in order that a sufficient amount of light may be received from the poorly illuminated page. Thus the radial and circular muscles are acting at the same time in opposition to each other, and the result is a disastrous muscular strain.

The Retina.—The third coat of the eye is the retina, which is a nervous coat. The retina is a very complex organ, composed of 10 layers, only three of which may be considered as layers of neurons. There are in the retina three layers of neurons in which the nervous impulse is started and by which it is transmitted. The rod and cone layer is the most important, and is the one farthest away from the center of the eye and nearest

the choroid coat. It is called the rod and cone layer in

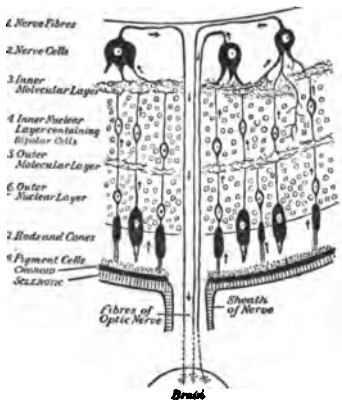


Fig. 14—Section of the retina showing three layers of neurons.

consequence of the two kinds of elements that are found in it. It seems to be necessary for the light to pass through the rod and cone layer before any impulse can be established.

The Fovea.—The point which is immediately behind the pupil in the retina is called the fovea centralis, or macula lutea, or yellow spot. It will be convenient for us to speak of it as the fovea. It is the point of most acute vision, and is the spot on which we try to make the image of an object fall when we turn our eyes to an object. In this fovea there are only cones. In that portion of the retina farthest away from the fovea there are only rods, while in an intermediate zone there are both rods and cones.

The Blind Spot.—An impulse which is started in the retina reaches the optic nerve and is transmitted by that nerve to the brain. The point at which the optic nerve enters the eye, or comes into contact with the retina, is

Fig. 15—Diagram to demonstrate the blind spot. Hold the diagram perfectly horizontal, the head erect, close the left eye, look steadily at the cross, vary the distance of the diagram from the eye, and the white circle will disappear.

called the blind spot. It is a place in which neither rods nor cones occur, and an image of an object falling upon the blind spot establishes no impulse. In every field of vision there is a portion that is vacant, although it is difficult for us to realize that we are not seeing all that we think we see. The blind spot is on the side of the retina nearer the nose than is the fovea.

The Crystalline Lens.—Returning now to the front of the eye and enumerating the different parts that we encounter in passing from the front to the back, we find first, the cornea; second, a cavity that is filled with a watery fluid called the aqueous humor, which fills the cavity in which the iris is placed. Next we notice the iris and the pupil, after which we come to the crystalline lens. This is a double convex lens, rather more convex toward the back than toward the front. It is enclosed

in a thin, transparent sac called the suspensory ligament. All around the edges of the suspensory ligament are fine muscular fibers called the ciliary muscle, which by their contraction, stretch the suspensory ligament out at the edges, and tend to bring the two layers of it closer together at its center, thus making the lens which is enclosed within them flatter. This flattening of the lens is just the condtiion necessary to enable it to bring the rays of light that come from a distant object, and are therefore more nearly parallel than those which come from a shorter distance, to a focus on the retina. When we look at an object near by, the ciliary muscles are relaxed, and the elasticity of the lens restores it to its former conxevity, which is the condition necessary to enable the rays of light from a near-by object to be brought to a focus on the retina.

Another Explanation.—The above is Helmholtz' explanation of the process of adjustment of the crystalline lens. It should be mentioned that another explanation of the action of the ciliary muscles is offered by other physiologists, in which it is the contraction of the muscles that renders the lens convex, and the relaxation that permits it to become flatter.

Vitreous Humor.—Behind the crystalline lens is a large cavity filled with a jelly-like substance called the vitreous humor. The word vitreous means glassy, and the vitreous humor is glassy and jelly-like, not at all like the aqueous humor. The other part of the eye, which is really not a part of the eye at all, is the optic nerve.

We have now indicated 10 parts of the eye, or organs that are immediately connected with it. The sclerotic coat, choroid coat, retina, cornea, aqueous humor, iris, pupil, vitreous humor, crystalline lens and the optic nerve.

Luminiferous Ether.—The eye is the machine. The power that acts upon it is the force of light. It is by means of light that we see, and it is the light acting upon the eye that establishes the nervous impulse. Light consists of vibrations in the luminiferous ether, which is an extremely thin and tenuous form of matter, that can not be detected by any of the senses. It can not be seen or felt or heard. The only way we become aware of its existence is by the behavior of other things. The presence of such a substance is necessary to enable us to explain the phenomena of light, radiant heat, electricity, and perhaps gravitation.

Light.—Luminiferous ether extends certainly as far as the most distant star that we can see, and we do not know how much farther. Light consists of waves in the luminiferous ether. The waves are transverse like the waves of water. If a ray of light is traveling across a room, the waves of which it is composed vibrate transversely across the path of the ray. The waves are very small. A ray of red light consists of waves that are about 1/33000 of an inch in length, and a wave of blue light is about 1/68000 of an inch. That is, in one inch there are about 33,000 red waves and about 68,000 blue waves. Waves of ether that are longer than 33,000 to the inch are not able to start an impulse in the retina, and waves

that are shorter than 68,000 to the inch are equally ineffective.

Vibration Frequencies.—Light travels at the rate of about 186,000 miles in a second. If we multiply 186,000, the number of miles, by 5,280, the number of feet in a mile, and that product by 12, the number of inches in a foot, and that by 33,000, the number of red waves in an inch, or by 68,000, the number of blue waves in an inch, we shall find that not far from 392 trillion red and 760 trillion blue waves enter the eye in a second. Between these two extreme numbers are all the other vibration rates, and they correspond to the other colors.

Force of Light.—Light exerts a force on the surface upon which it strikes. The force exerted is very small; in case of sunlight it is scarcely more than a milligram on a square meter, but that force, small as it is, is sufficient to jar loose from the very complex molecules that constitute the nerve tissue of the retina, some of the atoms that compose it, thus originating a nervous impulse. The impact of the ether waves is sufficient to jar the molecules enough to drive off some of the atoms from their connections with the other atoms in the molecule, thus setting some of the atoms free, which immediately strike the next molecule, driving off from it other atoms, and taking their places. The atoms that are freed from the second molecule strike the third, setting some of its atoms free and taking their places.

It will be seen from this that the atomic constitution and structure of the first molecule may be changed, while

the composition of the second and third remains practically unchanged, although some of the atoms may be different, and the arrangement is not the same.

Mechanical Theory.—The above may be called the mechanical theory of the origin of the nervous impulse. It is possible, of course, that instead of the atoms being driven away from the first molecule, that their arrangement merely is changed. The first supposition seems more probable, for it is difficult to see how a mere change in the arrangement of the atoms of one molecule can bring about a rearrangement of the atoms in the second and third molecules with which it is not in immediate physical contact.

Chemical Theory.—Another theory of the origin of the nervous impulse is the chemical theory, which assumes that the action of light waves upon some substance in the retina produces a chemical change similar to that which is produced in the film of a photographic plate. This chemical process serves as the means for bringing about a change in the first molecule, which is transmitted to the succeeding molecules.

Mechanical and Chemical Identical.—But recent discoveries in physical chemistry show us that all chemical processes are merely mechanical changes in the arrangement or composition of the parts of a molecule or the atom, so that at present there is no essential difference between a chemical and a mechanical theory of molecular changes. The mechanical theory described above seems to explain everything in a satisfactory manner.

Course of Transmission.—When an impulse has been established in the neurons of the rod and cone layer, it is transmitted to the optic nerve, and from there it passes along the nerve and over different portions of the nervous tract to the center for sight in the occipital lobe of the cerebrum.

The Chiasmus.—The impulse passes first over the optic nerve until it comes to a place where the optic nerves from both eyes join. This place is a kind of nervous knot called the chiasmus. From the chiasmus the nervous conductor proceeds backward as two nerves, but each is now called the optic tract, right and left, to distinguish them from the right and left optic nerves. The impulse passes back over the optic tract until it reaches the brain in a portion that might be said to correspond to the optic lobe. In fact, however, the fibers of the optic tract reach three different organs, or portions of the brain; the external geniculate body, the anterior corpus quadrigeminum, and the pulvinar of the optic thalamus. From these organs, the impulse is carried by fibers back to the optical center in the occipital lobe.

Decussation of the Fibers.—There is one peculiar feature in the distribution of fibers to the retina. The fibers of the right optic tract divide in the chiasmus, some of them going to the right side of each retina, while the fibers from the left optic tract reach the left side of each retina. So each retina contains fibers from both tracts. If we were to sever the right optic nerve, we should be blind in the right eye, and would see perfectly well with

the left. But, if we were to sever the fibers of the right optic tract, we should be half blind in each eye. We should be able to see any object that formed an image on the left half of the retina in either eye, but would be

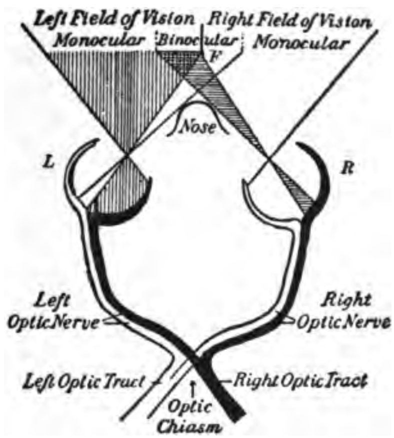


Fig. 16—Distribution of fibers from the optic tracts to the two retinae.

able to see nothing that formed an image on the right half of either retina.

In fishes and frogs the two optic tracts cross but do not form a chiasmus. There is no neecssity for distinguishing the optic nerve from the optic tract. But in mammals, bird and reptiles a chiasmus is formed.

DEFINITIONS

Eye—The apparatus by which light establishes a nervous impulse.

Sclerotic Coat—The outer one of the three coats of the eye.

Choroid Coat—The middle coat of the eye.

Retina—The interior, nervous, coat of the eye.

Iris—The colored portion of the eye.

Rod and Cone Layer—One of the three layers of neurons in the retina.

Blind Spot—A spot in the retina where the optic nerve enters the eye, destitute of rods and cones, and in which light will not establish an impulse.

Fovea—The center of the retina. The point of most acute vision, directly behind the pupil.

Light—A series of transverse vibrations in the luminiferous ether, between 392 trillions and 760 trillions per second.

Crystalline Lens—The principal refracting medium of the eye.

Ciliary Muscle—The muscle that adjusts the crystalline lens.

Optic Nerve—The nerve that transmits impulses from the retina to the chiasmus.

Optic Tract—That portion of the nervous transmitter that lies behind the chiasmus.

Chiasmus—The nervous knot in which the two optic nerves meet.

CHAPTER VI

THE SENSATION OF SIGHT.

That a center for color vision distinct from the visual center exists in the cerebral cortex, is rendered probable by the occurrence of hemianopsia for colors, and also by the experiments of Haidenhain and Cohn on the influence of hypnotic trance upon color blindness.—*Am. Txt. Bk., Volume II, p. 339.*

It is probable that children distinguish grades of light and shade rather minutely before the perception of colors is much developed.—*Hall's Adolescence, Volume II, p. 33.*

White Light.—Whenever a nervous impulse is established in the retina, or in any other part of the optic conductor, and is transmitted to the sight center in the brain, we experience the sensation of sight. When we look at a white card, or any other white object, we experience a sensation that we call white. When we look at the blackboard, we experience a different sensation that we call black. The white card is white because it reflects white light to our eyes. By white light we mean light that contains all vibration frequencies from 392 trillions to 760 trillions in a second. But the black object also reflects white light. In the light reflected from the blackboard will be found all vibration frequencies within the light limits. The difference is that the white object reflects more of the light that falls upon it than does the black object.

Difference Between White and Black.—An object that we call white reflects from 50 to 90 per cent of all the

light that falls upon it. An object that we call black reflects from less than one-half per cent to something more than 2 per cent. If the black object should reflect no light to our eyes it would be invisible. If the white object should reflect all the light that falls upon it, without any change, it would be a perfect mirror and would itself be invisible.

Gray.—Black and white, then, while they are two distinct sensations, are merely the extremes of a series of sensations accompanying impulses established by the reflection of various proportions of light of all vibration frequencies to our eyes. If the proportion of light becomes less and less, we cease to regard the body as white, and call it gray. We may have a light gray at first, and as we diminish the proportion of light that is reflected, the gray becomes less and less light until we say that it is a dark gray. If the proportion continues to decrease, the gray becomes darker and darker until we call it black. Somewhere in the series is a gray that we can call neither light nor dark gray. This is neutral gray. It is possible for a good eye, well trained, to distinguish 200 degrees of intensity in the sensation from black to white, or 200 degrees of brightness.

Brightness the Original Sensation of Light.—It is believed that in the beginning of sight, the first animals, and even the first men, could distinguish only black, white and gray. Men would then see things as a photograph shows them now. The perception of color came as a later acquisition. In fact, it is questionable whether

little children, perhaps up till the age of 3 years, can distinguish color, and whether they do not see things as merely black, white and gray. So when we find persons that are color blind, and unable to distinguish color, we may explain it by supposing that they have inherited that ancestral condition.

The Solar Spectrum.—If we set a triangular prism of glass in the sunlight at a window, we may throw on the opposite wall a spectrum of color. There will be observed in this spectrum the seven so-called primary colors, beginning with red and running through orange, yellow, green, blue, indigo and violet. The prism separates the different colors according to the wave lengths of light which compose them, or according to the vibration frequencies which they represent.

Number of Colors.—We ordinarily speak of only seven colors, but there is really no reason for limiting the colors to this number. Orange is certainly only a mixture of red and yellow, and there is no place in the spectrum for purple. The different colors are produced by different vibration frequencies, and there are many more than seven in passing from 392 trillion to 760 trillion. There is the possibility for as many different colors as there are vibration frequencies, but the eye is incapable of responding to such delicate differences as would be implied by this number. We shall find, however, that a good eye is capable of discriminating about 150 different colors, and this would mean that in order to constitute a difference in color, there must be a difference in vibra-

tion frequency of at least two and a half trillion vibrations per second.

Bright and Dull Colors.—The impulse accompanying a given color sensation is produced by rays of light of a single, or very limited, range of vibration frequency. But if there are many such rays, the sensation is intense, and we say that the color is bright; while if the number of rays are few, the sensation is feeble and the color is dull.

Color Blindness.—Some persons can not distinguish color, and hence are called color blind. In much the larger number of cases the color blindness is only partial, being limited to one or two colors. The most common form of color blindness is the inability to distinguish red, although some persons are unable to distinguish either red or green or blue. About four men in a hundred are color blind, while there is a much smaller proportion of women.

Color a Function of the Cones.—It is possible to demonstrate that we are all color blind in parts of our eyes. If we look at a point on the blackboard steadily, while another person holds a card, having upon it a red spot, at one side of the point at which we look, the image of the red spot will fall upon the retina at various distances from the fovea. When the image falls upon the fovea, we distinguish the color. When it falls upon some portion of the retina in the vicinity of the fovea, we are able to distinguish the spot, and to see its color. But if it is carried still farther to one side, the color disappears, while it may still be seen as a black or gray spot. The color is perceived only when the image falls upon that portion of

the retina in which the cones are found. When it falls upon any portion in which only rods appear, no color is perceived.

Rods Adjustable for Dim Light.—We can see color clearly only in a good light. When we look at color in a dim light, it is difficult to distinguish red from green or blue or yellow, except as one is darker or lighter than the other. But we can distinguish objects readily, as black or white or gray, even when nearly all the light has disappeared. It seems as if in the rods there is some means for making wide adjustments for the small amount of light, while in the cones there is no such adjusting power. It is in consequence of this fact that we are able to perceive the faintest possible object, such as a faint star, not by looking directly at it, but by looking a little bit to one side of it. This is what the astronomer calls the method of averted vision.

Positive After Image.—If we look steadily at a lighted window from the inside of the room for one second, and immediately close our eyes, we shall have the image of the window persisting in our eyes for a few seconds. The window will appear just as it was in the original image; the panes will be light and the sash dark. This phenomenon is called the positive after image.

Negative After Image.—If we look steadily at the same window for about 20 seconds, and then close our eyes, we shall see an after image, but the conditions will be reversed. The panes will appear dark and the sash

will be light. This is called the negative after image.

Complementary Image.—If we look steadily at a red spot on a card for 20 seconds, and then with our eyes open look at a gray or white wall, we shall see a green spot of the same shape as the red spot. This is called the complementary image.

Hering's Theory.—In order to explain the phenomena of after images and complementary images, Hering supposes that there are three different kinds of substances in the eye. One kind he calls the white-black substance, not because it looks black or white, but because by its decomposition under the influence of light it gives us the sensation white, while by its recomposition after it has been decomposed, it gives us the sensation black. It is decomposed by white light, and is recomposed by the absence of light. If decomposition and recomposition go on at the same rate, at the same time, we experience the sensation of neutral gray. So any shade of gray, or any degree of brightness, is dependent upon the relative amount of decomposition and recomposition going on at the same time in the black-white substance.

Red-Green and Yellow-Blue Substance. — Another substance is the red-green substance, whose decomposition gives rise to the sensation of red and its recomposition to the sensation of green. The third is the yellow-blue substance, whose decomposition gives rise to the sensation of yellow, and its recomposition to the sensation blue. Any color with any degree of brightness may

be accounted for by supposing that decomposition and recomposition are going on in all these substances at any time, in varying degrees and in varying proportions.

How Explain After Images.—The positive after image is seen because decomposition is going on in the black-white substance for a little time after the light is shut off, and decomposition goes on more rapidly than recomposition. But after having looked at the window for a period as much as 20 or 30 seconds, so much of the black-white substance has been decomposed that when the light is shut off from the eye, recomposition proceeds more rapidly than decomposition in that portion of the retina on which the image of the panes fell; while in that portion of the retina on which the image of the sash fell the amount of decomposition has not been so great; hence recomposition is not going on so rapidly as it is in the portion where fell the image of the panes. So in the after image, the panes look dark and the sash light.

Young-Helmholtz Theory.—Another theory, known as the Young-Helmholtz theory, does not consider the recomposition of the substances as giving rise to a sensation at all. According to this theory, there are three substances, red, green and blue. The decomposition of any one of these substances by the light waves of the particular length that are alone capable of affecting it, gives rise to the appropriate sensation. The decomposition of all of them in the same degree gives rise to the sensation of white, and all other color sensations are produced by the

decomposition of two or three of them in varying proportions.

How Explain Complementary Image.—In the complementary image, formed as in the experiment described, the red substance in that portion of the retina on which the image of the red spot fell, has been mostly decomposed; while the green substance in the same area has scarcely been affected by the red light. When we look at the white wall afterward, both red light and green light fall upon that same spot, but the red light finds little red substance to decompose, and the green light finds much green substance. So there is a preponderance of the green sensation, with not enough of the red sensation to neutralize it and make it white.

Neither Theory Satisfactory.—Neither the Hering theory nor the Young-Helmholtz theory can be considered satisfactory, although they are probably the best we have. The Hering theory has been believed to be more nearly satisfactory than the other. Both of them are chemical theories.

Four Color Senses.—It seems that in order to establish a satisfactory theory of color vision, we must recognize the fact that there are at least four primary colors; red, green, blue and yellow. Each color depends upon the fact that a particular brain center is traversed by an impulse. There are in all probability at least four different brain centers for the color senses. An object appears to be of a particular color because the impulse

that is set up in certain cones of the retina is transmitted to its appropriate center.

Another Hypothesis.—Other colors are produced by the modification of the primary colors; that is, by the transmission of impulses through different cells belonging to the different centers at the same time. The question then turns upon what it is that constitutes the difference in paricular cones that permits one kind of light to affect one cone and not affect another. It is then necessary to suppose that the molecules that constitute the tips of different cones do not all have the same physiological or atomic structure.

How Explain the Complementary Image.—The formation of the complementary image could be easily explained upon this hypothesis. After a molecule has undergone the change that occurs in a nervous impulse for a short time, usually not more than a second, there is a necessity for its rest and recuperation. It ceases to be so easily susceptible to the influences that start the impulse. When the red light has acted upon the red elements in a particular spot for a few seconds, they become less susceptible to the action of the red light. The green elements have not been affected at all by the red light. When white light containing both red and green vibrations falls upon the spot in which the red elements have become fatigued, the green impulse is established, but the red impulse is established with a much smaller degree of intensity. Hence the green, being unmodified so much as usual by the red, appears green.

How Explain After Images.—A somewhat similar explantation will account for the after images. The action of a stimulus upon an unfatigued nervous tissue persists for a small interval of time, as can be seen when we whirl a stick with a glowing coal at its end. The glowing coal appears to be a circle of fire instead of a point. The persisting activity is greatest in a place where the original activity is greatest, until a certain amount of fatigue has been accumulated, after which it is least. Hence we have the positive after image first, followed by the negative.

DEFINITIONS

White Light—Ether vibrations of all frequencies from 392 trillion to 760 trillions per second.

White—A sensation accompanying an impulse established by white light reflected in large amount from an object.

Black—A sensation accompanying an impulse established by white light reflected in small quantities from an object.

Gray—A sensation accompanying the impulse established by white light reflected in quantities between the black and white.

Neutral Gray—A gray that is neither dark nor light.

Brightness—The quantity of the sensation of sight depending upon the amount of light that establishes the impulse.

Color Blindness—The inability to distinguish color, while the ability to distinguish brightness is present.

After Image—The appearance of an object after the eyes have been closed. It is accompanied by a retinal impulse.

Positive After Image—That kind of an after image in which the relations of light and dark are the same as in the object perceived.

Negative After Image—That kind of after image in which the relations of light and dark are reversed.

Complementary Image—The image of a complementary color following the perception of a colored object.

Complementary Color—A color which when mixed with another will produce white or gray. Each color is said to be complementary to the other.

CHAPTER VII

THE SENSATION OF HEARING.

Each sense, or sensation, enables us to recognize only one quality of the objects which have made an impression upon it.—*Morat, Physiology of the Nervous System, p. 652.*

It can hardly be doubted that the nervous structures of the cochlea form an organ of special sense for the perception of musical tones, and perhaps for noises as well. But no trustworthy conclusion can be maintained as to the precise mode of action of the auditory apparatus.—*Am. Txt. Bk., Volume II, p. 380.*

The relation of the semicircular canals to equilibrium was first noticed by Flourens in 1824—De Cyon in 1874 was the first to speak of a sense of space, and connected with the more general conception of such a sense all the different experiments, including his own.—*Morat, p. 607.*

Hearing.—The next most important sense after that of sight is the sense of hearing. We shall need to study first the structure of the hearing organ, by means of which the impulse is established; second, the nature of sound; and third, the sensation itself.

External Ear.—The ear may be considered as composed of three parts, the external, middle and internal ear. The external ear is called the pinna, or concha, and is really of little use except as a support for ornaments. In some of the other animals this part is of considerable importance. Animals that pursue their prey, like cats and other carnivora, have the ear turned forward. Animals that flee from their enemies generally have the ear

turned backward. Man combines both characters, which

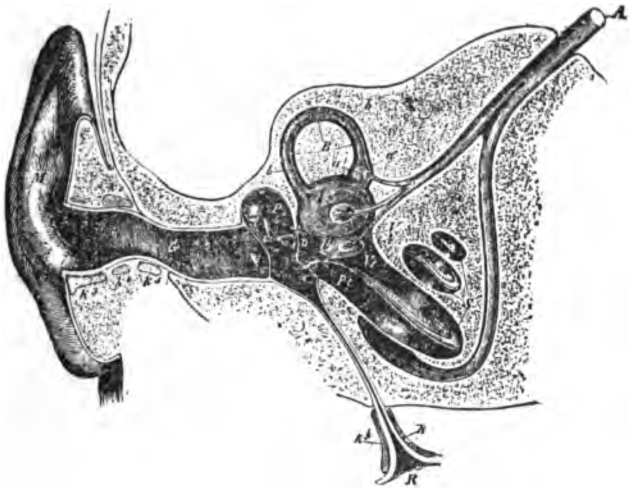


Fig. 17—Parts of the ear showing external, middle and internal ear; semicircular canals, cochlea, eustachian tube, vestibular and auditory nerves.

neutralize each other, and the position of his ear is not significant.

Muscular Adjustment of the Ear.—Some animals can adjust the position of the ear to the direction from which the sound comes. The muscle for the movement of the ears is found in all persons, but in nearly all it is vestigial, and in others it is only slightly functional. A few persons can move their ears slightly.

Auditory Meatus.—The other part of the external ear is the auditory canal, or the external auditory meatus. It is slightly bent, is about an inch long and terminates at the ear drum, or tympanum.

Middle Ear.—The middle ear is bounded outwardly by the tympanum, and on the other side by a bony partition that separates it from the internal ear. It is filled with air, and in order that the air may have the same pressure on the inside that exists on the outside, there is a narrow tube connecting the middle ear with the mouth. This is the eustachian tube, something over an inch long, opening into the back part of the mouth or throat, and so narrow that the air passes not very readily through it. When this tube is completely closed, the sense of hearing is likely to be dulled.

The Tympanum.—The tympanum is a thin membrane, but it is not merely a drumhead. A drumhead will respond to vibrations of only one rate, while the tympanum must respond to vibrations of all rates. Hence it is not merely a membrane stretched over a cavity. It is convex toward the middle ear and concave toward the outer. Its shape on the concave surface is more or less parabolic, and it is this shape as well as the muscular tension to which it is subjected, that permits it to respond to vibration rates of all frequencies, within limits.

Damping of the Tympanum.—A drumhead will continue to vibrate until it is brought to rest by its own inertia and by the resistance of the air. Such a condition in the tympanum would be fatal to good hearing. So the vibrations of the tympanum are damped, or stopped, by the attachment of a chain of bones to its inner surface, when the vibrations of the air on the outside that have set it into motion have ceased.

The Ear Bones.—The vibrations of the tympanum are transmitted across the middle ear by a chain of bones, attached to it on one side, and to a membrane that covers an opening through the bony wall of the internal ear on the other. The chain consists of three bones, called respectively the malleus, or hammer; the incus, or anvil; and the stapes, or stirrup. It is the malleus that is attached to the tympanum, and the stapes is attached to the membrane closing the fenestra ovalis, or opening through the bony wall of the internal ear.

Functions of the Bones.—These three bones do something more than merely transmit the vibration. They damp the vibrations of the tympanum, they transmit the vibrations, and they are attached to each other in such a way that they serve as multiplying levers, intensifying the vibrations that are transmitted to the membrane closing the fenestra ovalis. When these bones become anchylosed, or grown together, as they may in case of inflammation of the middle ear following a bad cold, the hearing is much impaired.

The Inner Ear.—The inner ear is contained in a cavity hollowed out of a bone of the skull called the mastoid process. The rounded prominence just behind the external ear indicates its position. The entire cavity is filled with liquid, the endolymph, and it is reached from the outside through an opening, the fenestra ovalis, which is closed by a membrane, and to which the stapes is attached. A vibration of the stapes will set the liquid which fills the internal ear into vibration. If the walls

of the internal cavity were perfectly rigid, the liquid could not be thus set into vibration; but there is another open-

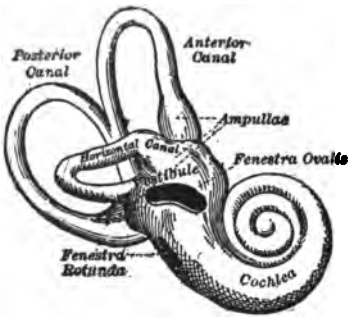


Fig. 18—The internal ear.

ing, called the fenestra rotunda, covered by a flexible membrane, which permits the endolymph to vibrate.

Two Organs in the Internal Ear.—The internal ear really consists of two parts containing two different sense organs, and giving rise to two different sensations. The one sense organ is the semi-circular canals, and the other is the organ of hearing. The two parts are continuous with each other, the same liquid fills both, and the vibrations which affect one equally affect the other. But their whole structures are different, and likewise are the sensations to which they give rise.

The Semi-circular Canals.—The semi-circular canals are three in number, and are placed approximately at right angles to each other. The sense located in them is the sense of equilibrium by means of which we may know when we are falling, or turning round. It gives rise, too,

to the sensation of dizziness. The fact that the three canals are placed at right angles to each other enables us to perceive our movement in every direction.

The Ampulla.—At the base of each semi-circular canal is a slight enlargement called the ampulla, and it is on the inside of the surface of this ampulla that the nerve fibers are distributed. These nerve fibers, which are extremely fine, project out into the liquid.

The Otoliths.—In this portion of the semi-circular canals, also, are to be found some very fine particles like sand grains, which, of course, are secretions, or concretions, produced in the ear, and called otoliths. When a movement of the body changes the position of the semi-circular canals, the liquid does not immediately take up the motion, and consequently the nerve fibers strike against the otoliths, or the vibrations so produced cause the otoliths to strike against the fibers, and the result is a nervous impulse, which is carried to the center of equilibrium in the brain. This kind of an organ is called a shake organ, and is found in crawfishes and many other animals. It is not properly called an ear. The nerve of the semi-circular canals is a different nerve from the auditory nerve. It is called the vestibular nerve, although both auditory and vestibular nerves follow approximately the same path to the brain, and constitute elements of the eighth pair of cranial nerves.

The Cochlea.—The organ of hearing is located in that part of the internal ear which is called the labyrinth, or

cochlea. It is shaped a good deal like a snail shell and turns about two and a half times around an axis, called the columella. It is filled with endolymph, and lined with

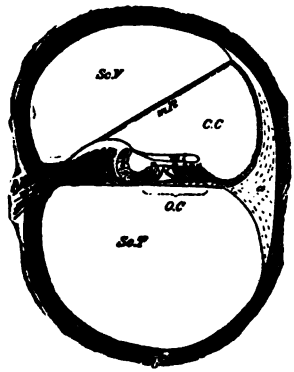


Fig. 19—Section of the cochlea showing its principal divisions and the organs located on the basilar membrane.

a membrane. About the middle of the cavity a bony shelf projects out from the columella, called the lamina spiralis. It follows the windings of the cochlea throughout its length. From its outer edge projects a membrane reaching to the sides of the cochlea along the outer wall. This is a basal, or basilar membrane.

Divisions of the Labyrinth.—From a point slightly back of the edge of the lamina spiralis and projecting rather upward and outward to the bony wall of the cochlea, extends a membrane called the membrane of Reissner. Thus the basal membrane and the membrane of Reissner divide the entire cavity of the bony cochlea into three cavities, parallel to each other and following its windings. The one below the basal membrane is called

the scala tympani; the one above the membrane of Reissner is called the scala vestibuli; while the cavity between the membrane of Reissner and the basal membrane is called the membranous cochlea, and is the only one that concerns us, for it contains the organ of hearing.

The Organ of Corti.—The most characteristic organ supported upon the basal membrane is the organ of Corti, which consists of two parallel series of cartilaginous rods, leaning toward each other, and forming between and under them a triangular tunnel called the tunnel of Corti. In the outer series of rods there are about 4,500 and in the inner series about 6,000. The close approximation of the number of rods to the number of tones that the human ear can appreciate led the early investigators to believe that each rod of Corti corresponded in some way to a separate tone. It is now known that such can not be the function of the rods of Corti, and the present belief is that they serve to damp the vibrations of the basal membrane, much as the dampers on a piano damp the vibrations of the strings.

How an Auditory Impulse Is Started.—The auditory nerve is distributed along the basal membrane and cells terminating in nerve cells and bearing nerve hairs rise from its surface, extending into the endolymph. There are two series of these hair cells, an outer and an inner series, ranged along the outer and inner sides of the organ of Corti. These nerve hairs of the outer series project up through openings in the reticulate membrane, which extends outward from the top of the organ of Corti.

It seems probable that the basilar membrane is set into vibration by the movements of the endolymph transmitted from the tympanum, and this vibratory movement of the membrane is communicated to the nerve hairs con-

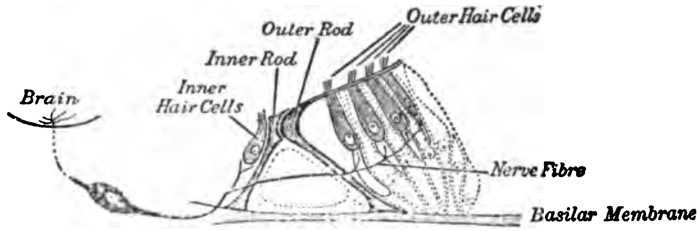


Fig. 20—Essential structures of the hearing organ located on the basilar membrane.

nected with it. These vibrations of the hair cells being opposed by the liquid, and perhaps by the edges of the openings of the reticulate membrane, establish an impulse which is transmitted to the hearing center in the temporal lobe of the brain.

Basilar Membrane a Selective Organ.—It seems that the basilar membrane is the organ that sorts out the different vibrations, responding in one part to the high tones and in anotherto the low; but the high pitched tones seem to affect the widest part of the membrane, so that the problem is a complex one, and is as yet very imperfectly understood.

Number of Sound Vibrations.—Sound itself consists of vibrations in the air. These sound vibrations differ widely from those which affect the eye and produce the

sensation of sight. The air is a much denser and coarser form of matter than is ether. The light waves are transverse, while the sound waves are longitudinal. The particles of air in a sound wave vibrate in the direction of the ray, not transversely across it. Light moves at the rate of 186,000 miles in a second, while sound moves at the rate of about 1,100 feet in a second. Instead of there being 392 trillion vibrations in a second as in light, the numbers of sound vibrations vary from 16 in a second to 76,000. In music, the extreme vibration rates are not employed. In an orchestra, the lowest and highest notes correspond to vibration frequencies of 40 and 4,200 respectively.

Tone and Noise.—We may draw a distinction between a tone and a noise. A tone is produced by regularly recurring vibrations of the same kind; while a noise is produced by irregular vibrations of different kinds occurring at the same time.

An Octave.—One note is said to be the octave of another when it is produced by twice the number of vibrations. Two notes so related can easily be recognized as resembling each other in some way. The note which, on the piano, is designated as middle C has a vibration frequency of 256, although in concert pitch it is 261. The octave higher has a vibration frequency of 512. This is the tone C-I. The interval between C and C-I is divided into seven intervals which require eight notes for their determination, and from this fact the entire series is called an octave.

Relative frequencies of Different Notes.—If we call the note C one of the scale, the other notes will have vibration frequencies represented by the fractions 9/8, 10/8, 4/3, 5/4, 3/2, 5/3, 15/8, and 2 respectively. These fractions will correspond nearly to the vibration rates of 256, 288, 320, 340, 384, 425, 480, and 512. If we observe the ratio of difference between each note and its successor we shall see that the differences are 32, 32, 20, 44, 41, 55, and 32. The interval between 1 and 2 of the scale is called a whole step, or major second, and corresponds to a difference in vibration frequency of 32. The interval betaween 3 and 4 of the scale is called a half step, or minor second, and corresponds to a difference in vibration frequency of 20. The interval between 7 and 8 of the scale is also called a minor second, and corresponds to a difference in vibration frequency of 32, which is exactly the numerical difference that corresponds to a major second between 1 and 2 of the scale.

Weber's Law.—This is as we should expect, or nearly so. To produce the octave of middle C we must add to its vibration rate 256. To produce the octave of C-1, we must add to its vibration rate 512. The psychological explanation of this phenomenon depends upon a principle that we shall discuss under the head of Weber's law. Briefly stated this is that in order to add equal amounts to the sensation, we shall need to add to the stimulus by increasingly larger amounts.

Pitch and Loudness.—Sounds differ in three respects: First in pitch, which corresponds to differences in vibra-

tion rates. Second in loudness, which depends upon amplitude of vibration. Amplitude means the difference in extreme positions of a single vibrating particle. It may be illustrated by stretching a string and then plucking it, causing it to vibrate. If the pluck, or stroke, be light, the middle of the string will not move very far from its rest position, and the sound will not be very loud. But if the pluck or stroke be stronger, the middle point on the string will be drawn much farther from its rest position, and the sound will be louder.

Timbre.—The third character of sound is its quality, or timbre. This is the character that enables us to distinguish a tone on the piano from a tone made by the human voice or a drum, or violin, even though it may have the same pitch and loudness.

Overtones.—The element of timbre depends upon the overtones. An overtone is an impulse established by the vibration of only a part of the vibrating body at the same time that the whole body is vibrating. A string may vibrate as a whole, but at the same time each half of the string may vibrate independently as a part, and each part may be divided into smaller vibrating units, having independent rates of vibration. The excellence of tone in an instrument depends upon the number and harmony of the overtones.

Distinguishable Pitch Differences.—The ear that is sensitive and well trained can distinguish very small intervals of pitch. It is believed that in the part of the

scale most easily covered by the human voice, from C-1 to C-3, in which the piano gives only 24 tones, the well trained ear can distinguish three thousand tones. This seems, however, like an extreme estimate, and much the larger number of persons do not have anything like that dgree of sensitiveness. Many persons fail to discriminate intervals of less than a third of a major second, and some persons are unable to distinguish the interval of a minor second, or even of a major second. In extreme cases a person may be unable to distinguish a major third or even a major seventh. Such persons are tone deaf and may properly be said not to know one note from another. It is believed, however, that a well trained ear is able to distinguish eleven thousand tones.

DEFINITIONS

Tympanum—The drumhead, or the membrane that closes the tube of the external ear.

Cochlea—The winding cavity of the internal ear in which is placed the organ of hearing.

Semicircular Canals—Three almost circular cavities connected with the ear in which is located the sense of equilibrium.

Otolith—One of the small particles in the semicircular canals whose agitation establishes an impulse in the endings of the vestibular nerve.

Organ of Corti—An organ composed of two series of cartilaginous rods located on the basilar membrane.

Lamina Spiralis—A bony shelf projecting from the columella.

Malleus, Incus, Stapes—Names of the three bones of the middle ear.

Eustachian Tube—The slender tube connecting the middle ear with the mouth.

Concha, Pinna—The external ear.

Basilar Membrane—A membrane attached to the edge of the lamina spiralis and supporting the hearing apparatus.

Sound—Vibrations of the air between the limits of 16 and 76,000 a second.

Tone—A sound consisting of regularly recurring vibrations.

Noise—Irregular vibrations of different kinds produced at the same time.

Ampulla—A slight enlargement at one end of each semicircular canal.

Endolymph—The liquid contained in the internal ear.

Fenestra Ovalis—The opening through the bony wall of the internal ear. It is closed by a membrane.

CHAPTER VIII

OTHER SENSATIONS.

We may suppose that for every area of peripheral distribution of tactile fibers in the skin, there corresponds an area of tactile nerve cells in the brain. It can hardly be doubted that the nerve cells are divided in physiological groups characterized by inherent and inborn quality differences in the sensations aroused by their respective excitements.—*Am. Txt. Bk., Volume II, p. 394.*

There is strong reason to believe that corresponding to the four primary taste sensations there are seperate centers and nerve fibers, each of which when excited gives rise only to its appropriate taste sensation.—*Am. Txt. Bk., Volume II, p. 412.*

This perception (muscular sensation) may be the outcome of a direct consciousness of motor energy sent out from the motor cells, or it may be due to the inflow of sensory impulses which show the tension to which the muscles have been subjected. The latter view has more to be said in its favor.—*Am. Txt. Bk., Volume II, p. 401.*

The heat spots are in their opinion (Blix and Goldscheider) locally distinct from the cold spots. No cold sensation can be produced in the former, no heat sensation in the latter. These observations are, however, not confirmed by Dessoir, and are theoretically so improbable that we may decline to accept them.—*Kulpe, Psychology, p. 94.*

It is probable that the sensations of cold and heat are referable to different forms of the excitatory process in one and the same nerve.—*Kulpe, Psychology, p. 94.*

The Five Senses.—It was formerly believed that there are only five senses: seeing, feeling, hearing, tasting and smelling. We have already discussed four: seeing, color, hearing and equilibrium. Each of these senses has a different end organ, different nerve, different stimulus, and

without any question, a different cerebral center. We shall see that there are many other senses.

Taste.—The sense of taste has for its end organ the termination of nerve filaments in the tongue. Upon the tongue are found various elevations containing nerve endings, called papillae. These papillae are of various forms, the most conspicuous of which are the circumvallate

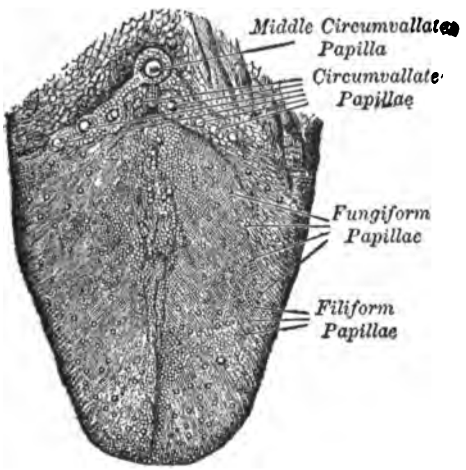


Fig. 21—Taste papillae of the tongue.

papillae at the back of the tongue, which look like little craters, and are the places in which are disposed some flask-shaped bodies, the walls of which are composed of nerve cells constituting the termination of the taste nerves.

salt, sweet, and sour. Salt, in order to be tasted, must be placed in solution on the tip of the tongue, or it must be dissolved in the saliva at that point. In whatever manner the tip of the tongue is excited so as to establish a nervous impulse, the resulting sensation is a salty taste. If the nervous impulse is started in the tip of the tongue by striking it with the finger, or with a glass rod, we shall experience the taste of salt. The tip of the tongue is innervated by a small nerve distinct from the gustatory nerve, which constitutes one of the branches of the facial nerve, and is known as the nerve of Wrisberg.

Where Located.—The bitter taste is experienced at the base of the tongue. If a bitter substance be placed at the tip of the tongue, it can scarcely be tasted at all. The base of the tongue is innervated by the gustatory nerve, which is a portion of the glosso-pharyngeal. The sweet and sour tastes are not so completely separated from the others, being located along the sides, and the sweet especially, being experienced at or very near the tip.

Taste Centers.—When a nervous impulse is established in a nerve of taste it is transmitted to some center in the lower portion of the temporal lobe. It can scarcely be doubted that there is a separate center in the temporal lobe for each of the four sensations, and consequently it would be perfectly proper to consider them as four distinct senses.

Smell.—The sense of smell is another one of the five senses originally distinguished. The end organ is in the

nose. The two sides of the nose are separated by a bony partition called the septum, from each side of which pro-

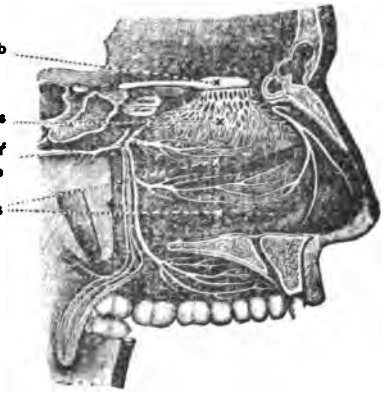


Fig. 23—Distribution of the olfactory fibers in the mucous membrane of the upper turbinate bone.

ject two curving bones, the upper and lower turbinate. The air that is breathed through the nose in an ordinary inspiration passes over the lower turbinate, and only slightly over the upper. This accounts for the fact that when we wish to smell a faint odor, we sniff, or make a forced inspiration, thus forcing the air in greater quantity over the upper turbinate, where the smell nerves are distributed, and bringing the odorous particles into contact with the nerve endings.

Odoriferous Molecules.—The particles of the odorous body which affect the sense of smell must be in a state of molecular division in the air; and only those substances which are capable of sending off particles in this finely divided state can be perceived. We cannot smell iron or

glass, because these substances do not evaporate, or send off molecules into the air in sufficient quantity to affect the nerve endings.

Olfactory Membrane Moist.—The mucous membrane which lines the nose is always moist, and if it should become dry the sense of smell could not be aroused. We may suppose that the molecular particles of the odorous body become dissolved in the moisture of the mucous membrane, when we have exactly the same conditions that prevail in the establishment of the taste impulse.

Similarity of Taste and Smell.—We thus see the close affinity that exists between the sense of taste and the sense of smell. The end organs are located very close together, both have their nerve endings terminating in the mucous membrane, which must always be moist before the sensation can be aroused, the particles that are tasted or smelled must be in a state of molecular division, and it is probable that it is the force of molecular vibration which establishes the nervous impulse in both. Both kinds of impulses are carried to the same lobe in the brain, and the brain centers are very close together.

Differences.—Although there are so many similarities between the senses of taste and smell, they are perfectly distinct. It is true that when the sense of smell is diminished the sense of taste seems to be diminished also in a very large measure, but this is probably on account of the fact that we often mistake something that is smelled for something that is tasted, in consequence of the odor-

ous particles reaching the olfactory nerve endings through the mouth and pharynx.

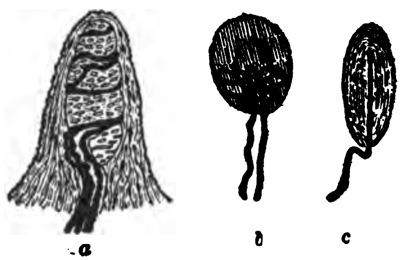
Modification of Taste by Smell.—But a more important consideration may be discovered in the fact that when two sensations are experienced together they modify each other; and in many cases the modification consists in the intensification of both. This principle will be discussed more fully in the following chapter, but it needs to be mentioned here, for it has never been sufficiently considered in the explanation of the fact that a decrease in the acuteness of smell diminishes the intensity of taste. A smell sensation, experienced at the same time with a sensation of taste, will intensify the taste.

Smell in Man and Dog.—The sense of smell is probably a decadent sense in man, and primitive man probably possessed a much more acute sense of smell than does his modern descendant. Our sense of smell is not of very great importance to us, and our mental furnishings include very few smell pictures. If we examine the nose of a dog, we shall find that the ramifications of the turbinate bones and cartilages are a thousand times as complex as they are in man, and it is probable that the sense of smell in a dog is a thousand times as acute. The mental furnishings of a dog must include a great many smell pictures.

How Many Smell Sensations.—We can smell a great many things, and it is a question how many sensations of smell we may distinguish. Some psychologists indicate nine different sensations, but the probability is that we

have the rudiments of a great many more, all of them so slightly differentiated from each other that it is scarcely woth while to classify them. We might just as well say that we experience only one sensation of smell as to say that we experience forty.

Touch.—The fifth sense of the originally recognized five is the sense of touch. The nerve endings of the sense of touch are located in the skin, although they are not limited to it. They exist in the mucous membrane, the mesentery, and even in the ends of the bones. The most characteristic end organs of touch consist of a series of touch corpuscles of several distinct kinds, situated under



a b c

Fig. 24—Different kinds of touch corpuscles.

the epidermis in the true skin. They are very small and so numerous that it is difficult to set the point of a pencil down anywhere on the skin without its coming into contact with one or more touch corpuscles. The contact of any foreign body with a touch corpuscle is sufficient to establish an impulse in the nerve ending, which is transmitted to the touch center in the brain.

How Measure Its Delicacy.—The sense of touch is more delicate in some parts of the skin than it is in others. Its sensitiveness is measured by the distance to which the points of a pair of dividers must be opened in order that they may be felt as two when both are placed on the skin. In this way it is found that the most sensitive place is the tip of the tongue, and next the tips of the fingers. The back of the neck is little sensitive, and still less so is the skin of the back. The points of the dividers must be placed at a distance of nearly two inches in order that they may be felt as two on the skin of the back.

Explanation of Difference in Delicacy.—The explanation of this phenomenon is not easy. It would seem as if the two points would be felt as two if each point rested on a different corpuscle, or if each rested within the circle of influence of the two corpuscles. But this would mean that when the two points were in the field of influence of the same corpuscle they would be felt as one. It would then frequently occur that the two points would be felt as two when they were close together and in different fields, while they would be felt as one when they were in the field of the same corpuscle but farther apart. If they were merely across the dividing line that separates the field of one corpuscle from that of another, they would be felt as two, even though the distance might be very small. There seems to be no evidence of such an arrangement. The distance that the dividers must be separated seems to be constant at any time in any given area.

Touch the Primitive Sense.—The sense of touch has for its brain center a cortical region just behind the

motor area in the parietal lobe, and there seems to be some evidence that the two areas overlap. Touch gives us information of the roughness or smoothness of a surface, and is best exercised by moving the surface over the skin, or the skin over the surface that is touched. It is the most widely diffused of any of the senses, and seems to be the general or primitive sense out of which the others have been developed, and of which they are merely the specialized manifestations.

Physical Contact Necessary.—We have seen that the object that is felt must come into contact with the touch corpuscles directly, or indirectly through the epidermis, before a nervous impulse can be established. Similarly the substance to be tasted must come into contact in a state of molecular division with the nerve endings of the sense of taste. The particles of the odorous substance in order to be smelled must come into contact with the nerve endings of the olfactory nerves. It is this mechanical impact of the particles in a state of molecular division that establishes an impulse in the end organs of taste and smell.

Physical Contact in Hearing.—In the same way the vibrating body must come into contact with the tympanum through the medium of the air before its vibrations can establish an impulse of hearing. Thus the vibrating body is in indirect contact with the nerve endings through the medium of the air, the tympanum, malleus, incus, stapes, the endolymph and the basal membrane.

Physical Contact in Seeing.—In like manner the eye comes into contact with the luminous body, or the illuminated body, through the medium of the ether, and the nervous impulse is established by means of the vibrations which the luminous body sends off. It might be demonstrated in the same way that the sense of equilibrium depends upon the direct contact of the otoliths, with the nerve endings, although this sense differs from the others in the fact that the information gained through it concerns the state of our bodies.

Every Sense a Modification of Touch.—So in a general way we may assert that in order to establish an impulse in any organ, the object that establishes the impulse must touch the organ, directly or indirectly, and exert upon it some mechanical force, of one kind or another. This makes every sense be a sense of modified touch.

Temperature.—A seventh sense is the sense of temperature. The end organs are nerve endings in the skin, and as a result of their location, the sense of temperature has for a long time been confounded with the sense of touch. We put our hand on a warm stove, and not only do we feel that it is smooth or rough, but we also feel that it is hot. But the immediate contact which is necessary for the sense of touch is not necessary for us to experience the sense of temperature. When we hold our hand near a hot stove, or a hot iron near our cheek, we experience the sensation of temperature without coming into immediate contact with the hot surface. Nor is it

the contact of the heated air that is necessary to give rise to the sensation. We may experience the sensation of temperature when we hold our hand beneath a heated body, and in this case the air is rising from our hand to the heated body, rather than going from the heated body to our hand.

Heat Ether Waves.—The medium through which the temperature of the substance affects the endings of the temperature nerves is the ether. In this respect the temperature sense is more nearly like the sense of sight than it is like the sense of touch. The ether waves that establish the temperature impulse are longer than the light waves.

Hot Spots and Cold Spots.—In the skin we find spots which when irritated give us the sensation of heat, and other spots which give us the sensation of cold. We may call these the hot spots and the cold spots. The sensation may be aroused by exciting the spots on the skin by the fine point of a pencil, but the better way is

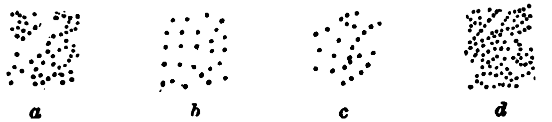


Fig. 25—Distribution of (a) heat spots; (b) cold spots; (c) small hairs; and (d) touch spots over the same small area of the skin, ten millimeters square.

to search for them with the fine point of a copper tube filled with hot or cold water. When we touch the hot spot with the hot point, we experience a sensation of heat.

If we touch the cold spot with the heated point, we get no sensation. Similarly, the hot spot will give no sensation when touched with the cold point, or, the sensation will be exactly the same that it would be if the hot spot were mechanically excited with the point of a pencil. When we stimulate a touch corpuscle with such a hot or cold point, we experience a sensation of touch only, not one of temperature.

Muscular Sense.—Another sense, which we may call the eighth, is the muscular sense, or the sense of resistance to muscular effort. When we hold a weight out at arm's length we experience a sensation whose impulse originates in the muscle. Whenever a muscle contracts it starts an impulse which is transmitted backward to the brain and accompanies the sensation of muscular resistance. It is the most delicate means we have for determining the weight of the body, and we may say that this muscular sense gives us information of weight. Its end organ is in the muscle itself, and the brain center is undetermined, although it is probably in or near the motor area.

Pressure Sense.—Another sense is the pressure sense, which is distinct from the muscular sense. By it we may ascertain the weight of a body, but this means of estimating is not so delicate as is that of the muscular sense. We may illustrate the difference by placing a rather heavy body on the hand and holding it out at arm's length. When we are holding it in this manner, we are experiencing the sensation of muscular effort and that of

pressure. Now if we let the hand with the weight upon it rest upon the table, we are no longer experiencing the muscular sensation, but the sense of pressure is experienced alone. It originates in the skin, and in the ends of bones, and no special end organs or brain centers are known for it.

Strain.—The tendons are organs by means of which the muscles are attached to the bones. When we exert the muscle so strongly that the tendon is injured, or its connection with the bone is threatened, we feel a soreness that arises from the injury to the tendon and we say that the tendon is strained. A strain is any sensation that arises from the tendon, and it does not need to be so intense as to constitute an injury. We know nothing about the brain center for strain, nor nerve endings, nor strain nerves.

Kinaesthetic Sensations.—The three sensations, muscular, pressure and strain, are all of them experienced when we hold a weight at arm's length. They are closely associated with movement of many kinds, and are so frequently experienced together that they are sometimes classed under the same head as kinaesthetic, or movement sensations.

Hunger.—All the senses thus far studied have given us information of bodies outside of ourselves. But there are senses whose principal function is to give us information concerning the state of our own bodies. The first of these is the sensation of hunger, whose end organ is the

stomach, and whose nerves are filaments from the sympathetic system. It gives us information concerning the condition of our bodies with respect to food and the need for the same. We know about this sensation and learn of the need for food by means of the connection which the sympathetic nerves have with the brain.

Thirst.—Almost the same thing may be said about thirst. This sense gives us information concerning the state of the body with reference to the condition of the fluids in it. A person who loses much blood experiences an intense thirst, and profuse perspiration quickly induces the same sensation. The end organ is located in the back part of the mouth and the top of the throat. Its nerve association is with the sympathetic system through whose connection with the brain we learn of the sensation.

Nausea.—The sense of nausea is located principally in the upper part of the esophagus. When the upper part of the esophagus, or back part of the throat, is irritated, we experience a sensation, and its reflex is a reversed action of the muscles of the stomach and esophagus. The usual direction of the contraction is from above downward. Under the influence of the sensation of nausea, the muscular contraction begins at the bottom, and proceeds upward. The nerve connection is with the sympathetic, and through that with the brain.

Number of Senses.—We have now enumerated thirteen senses, each of which arouses in us one or more sensations which are specifically distinct. We might

greatly extend the number. Instead of one sense of color, it would in all probability be perfectly legitimate to distitnguish four. Instead of one sense of taste, it is perfectly proper to call that sense four. Besides this, it is easy to extend the list to twenty-eight or twenty-nine distinct sensations, each in all probability having its own brain center and end organ. However there seems little to be gained by trying to discriminate such a large number. It seems probable that there are in the human organism the beginnings or rudiments of many sensations and sense organs, but they are differentiated so slightly that there seems little to be gained in trying to define them. The old hierarchy of five senses, however, is no longer tenable.

Pain Not a Sensation.—Many psychologists speak of pain as a sensation, and distinguish a pain sense with pain nerves, pain end organs, and a pain brain center. Goldscheider, who discovered the hot spots and cold spots in the skin, believed that he had also discovered pain spots. Goldscheider's observations have not been confirmed and there are no corresponding pleasure spots. It seems altogether improbable that there can be any distinct pain sense, since pain is experienced in the activity of every sense when the stimulus becomes greater than a certain amount, and the sensation attains a high degree of intensity.

DEFINITIONS

Taste-Papillae—The end organs of the sense of taste.

Taste Buds—The terminal nerve endings located in the papillae.

Turbinate Bone—One of the two small curved projections of bone on each side of the septum of the nose.

Olfactory Nerves—The nerves of smell.

Gustatory Nerves—The nerves of taste.

Hot Spots—The points in which are located the terminal filaments of nerves in which are established the impulses accompanying the sensation of heat.

Cold Spots—Those in which are established the impulses accompanying the sensation of cold.

Kinaesthetic Sensations—Those of the muscular, tendon and joint sensations. These are principally concerned in movement.

CHAPTER IX

SENSATION.

Of all these phenomena, sensation is the most elementary. This is the original fact from which all others are derived by extensions, associations, dissociations or different combinations. In itself it is simpler than it appears to be. A sensation may be isolated from every other to such a degree as to leave no trace behind it.—*Morat, p. 650.*

If our feelings resulted from a condition of the nerve molecules which it grew ever more difficult for the stimulus to increase, our feelings would grow at a slower rate than the stimulus itself—Weber's law would thus be a sort of law of friction in the neural machine.—*James, Psychology, Volume I, p. 548.*

The latest and probably the most real hypothesis is that of Ebbinghaus, who supposes that the intensity of separation depends upon the number of neural molecules which are disintegrated in the unit of time.—*James, Volume I, p. 548.*

I see no alternative but to affirm that the thing primarily known is not that a sensation has been experienced, but that there exists an outer object. Instead of admitting that the primordial and unquestionable knowledge is the existence of a sensation, I assert contrariwise that the existence of a sensation is an hypothesis that cannot be framed until external existence is known.—*Spencer, Psychology, Volume II, p. 369.*

We are thus driven to conclude that our sensations primarily differ because different central nerve organs in the brain are concerned in their production.—*Martin, Human Body, p. 471.*

We are pretty sure that a man, the inner end of whose optic nerve was in physiological continuity with the outer end of his auditory, and the inner end of his auditory with the outer end of his optic, might hear a picture and see a symphony.—*Martin, Human Body, p. 472.*

We are therefore justified in supposing that the nerve fibers and their central terminations are indifferent structures, physiologically

capable of the most diverse functions, and that their specific character is imposed upon them from without. In other words, the excitations of the central organs are functions not intrinsically localized, but altogether dependent upon internal and external stimulation.—*Kulpe, Psychology, p. 84.*

Psychology.—With our present chapter, we enter the domain of psychology proper. Heretofore we have been engaged so completely with the physiology of the subject that the psychological aspect has not been at all prominent. Now, however, it begins to take the leading place.

Sensation.—We have been studying the different senses and sense organs and much reference has been made to sensation. We have had much personal experience with sensations, and can best begin our study of them by undertaking to discriminate sensation from all other kinds of experiences, and to state what a sensation is.

A Mental Process.—A sensation is a mental process, and by this statement we distinguish it from a nervous impulse, which is a physiological process. The physiological, nervous, impulse accompanies, and goes along with the mental process of sensation, but the two are clearly distinguishable. It is a convenient way to describe the sensation to say that it is the concomitant of the nervous impulse.

Sensation Simple.—But we need to discriminate a sensation from other mental processes, especially from those which are most nearly like it, such as the process that we call perception. The essential difference between sensa-

tion and perception is that sensation is a simple mental process, while perception is complex. A sensation in its simplest, purest form is the concomitant of the transmission of a nervous impulse through a single brain center, while a perception is accompanied by the transmission of an impulse through several brain centers, and is a combination of several sensations. Hence we may say that a sensation is a simple mental process.

Sensation a Knowing Process.—But there are other simple mental processes that are not sensations. Some feelings are as simple as are sensations. We need to distinguish sensations from some of the simple feelings. Simple feelings are sometimes called affections, or simple affective processes, by which is meant any kind of a process whose especial characteristic is pleasure or pain. It is not strictly correct to say that pleasure or pain is the affective process, but if we accept that as a tentative statement confessedly inaccurate, we shall be able to discriminate a sensation from it sufficiently to enable us to make a definition of sensation. A sensation is a process that makes us know, but does not make us feel. It makes us know the quality of an object. It is then a knowing process, an intellectual operation, and is thereby distinguished from a feeling process, or affection.

Sensation Subjective.—We now need to answer two other questions: What is a quality of an object, and how does a sensation enable us to know it? The sensation is in me, it is not in the object outside. I am really aware only of the sensation. If I handle a knife carelessly, I say

that I am hurt, and I experience a sensation that tells me of the fact. I do not say that the knife is hurt. If the knife has been out of doors on a cold day, and I hold it in my hand, I experience a sensation that leads me to assert that the knife is cold. Really it is not the knife that is cold, but it is I am cold. I am the one that experiences the sensation cold. Similarly when I taste sugar, I say that the sugar is sweet, but I am the one who is experiencing the sensation, and if we should express the fact properly, we should say that I am sweet. So when I look at a red object, I experience the sensation red, and if properly expressed we should say that I am red, instead of the object is red. The sensation is always subjective, not objective. It is in me, not in the object. Our names of sweet, cold, red, and the entire list of qualifying adjectives are names of sensations. How then does a sensation make us know a quality?

Qualities Correspond to Sensations.—I may look at a red book and experience the sensation red. So I may look at a red card, and half a dozen other red objects, and when looking at each one I experience a sensation similar to the sensation I experience when looking at any other. Hence I believe that there must be a similarity in the objects that corresponds to the similarity in my sensations.

Nature of the Correspondence.—But we need to ask what is the nature of that correspondence. The sensation red cannot be a picture, or an image of the quality. If we could examine the eyes, or the brain, with a psycho-

logical microscope, we should not find anything in it to correspond in appearance and structure to the quality of the object. The sensation is not merely a projection of the quality upon the brain or upon the mind. The real nature of the correspondence we shall probably be forever unable to state. We may say that it corresponds, meaning by that that whenever we come into contact by means of any of our senses, with the object which manifests this particular quality, the sensation always ensues.

Identity of Sensations Unprovable.—We cannot even be certain that the sensation aroused in us by any particular quality is similar to that aroused in another person by the same quality. If we may imagine one of my eyes exchanged for one of yours, and we were both able to see with the exchanged eyes; or if my brain center for sight were exchanged for your brain center, and we were both able to see after the exchange; or if both eye and brain center were exchanged, would each of us experience the same sensation under similar circumstances that we experienced before the exchange had occurred? There is no way of demonstrating the fact, if it be a fact. But under the same conditions we each experience a sensation to which we apply the same name, and the same sensation appears to each one of us at all times under the same conditions. We believe that there is something in the object that corresponds to our sensation, and that thing to which the sensation corresponds we call the quality. I use the name red to designate the sensation, but I transfer the name of the sensation to the quality that corresponds to it.

Definition of Sensation.—Our definition of sensation, then, is that it is a simple mental process that makes us acquainted with the quality of an object. This distinguishes it from an affective process, but it does not distinguish it from other intellectual processes such as idea, attention, memory and consciousness. We need to state some other characters of sensation that will distinguish it from these.

Physiological Concomitant.—The essential distinction between sensation and other intellectual processes can best be described in terms of the physiological concomitant. We call the process we are defining a sensation, and associate it with the senses and sense organs. A sensation always accompanies a nervous impulse that is established in a sense organ, or which originates upon the outside of the body.

Peripherally Initiated Impulse.—The outside of a sphere or a circle or other body, we designate as the periphery. So we may describe a nervous impulse that originates in a sense organ, on the outside, or periphery of the body, as a peripherally initiated impulse. When we sit down to think or remember, or reason, nervous impulses are traversing brain centers, but these impulses do not originate in sense organs, but in the brain centers themselves. We may call such impulses centrally initiated, and they accompany all mental processes except sensation and perception, which alone are accompanied by peripherally initiated impulses. Inserting this distinction into our definition we may say that sensation is a simple mental process which makes us acquainted with

a quality of an object, and which is the psychological concomitant of a peripherally initiated impulse.

Sensations Not Depend Upon Sense Organs.—It is our purpose next to inquire how one sensation differs from another, and upon what does the difference in sensations depend. We have already considered the senses of sight, hearing, taste and others, and we have seen that each sense has its own kind of sense organ. We shall very naturally expect that the difference in sensations depends upon the difference in the end organ in which the impulses originate. This is the notion expressed by Kulpe in the quotation at the begining of this chapter, but seems rather easy to demonstrate that such is not the case.

Illustration.—If the eye were removed from the head, a nervous impulse might still be established in the retina, but there would be no sensation of sight. If the nervous impulse were established in some other way than by the activity of the end organ, as has been done in some cases, we should still experience the proper sensation. We have all of us fallen down and bumped our heads, and have seen stars and constellations and a whole milky way; but the sensation did not come as the result of ether waves impinging upon the retina.

A nervous impulse is established by the jarring of the brain center, or the optic nerve, or perhaps by the jarring of the retina. At least, it is not the proper and ordinary action of the sense organ that sets up the impulse which accompanies the sensation of sight.

Centrally Initiated Sight Sensations.—If we press upon the eyeball with the finger, we experience the sensation of sight. If the optic nerve be pinched with a pair of forceps, we yet experience the sensation of sight. If we merely think, or try hard to remember how an object appeared when we once saw it, we can experience a sensation of sight, although it may be faint. However, some persons are able to project visually an image as vivid as a real object when seen. In such a case it appears evident that it is not the end organ which is concerned in the production of the impulse.

Function of a Sense Organ.—It appears that the end organ is merely a device by means of which a nervous impulse is established by its proper or specific kind of excitation. The eye is a device by which the extremely feeble ether waves are able to establish a nervous impulse. The ear is a device by which sound waves establish an impulse. The taste organs are devices by means of which the molecular solution establishes an impulse. So all that the sense organs do is to enable a nervous impulse to be established by different kinds of forces.

Sensation Not Determined by the Nerve.—It thus appears that we may eliminate the end organs from consideration, when we undertake to determine why one sensation differs from another. Is it then the nerve that determines what the sensation shall be? It was at one time supposed that the optic nerve would transmit only sight sensations; the auditory nerve auditory sensations only. It was believed that if it were possible to establish a sight impulse in the auditory nerve, that nerve would fail

to transmit it. This is the doctrine of the specific energy of the nerves. We now know that any nerve will transmit any kind of an impulse in either direction. The nerve itself is neutral. Whatever impulse is established in it, no matter by what means, whether it be the activity of its proper sense organ, by mechanical stimulation, or by electric shock, will be transmitted.

Are Determined by Brain Center.—We are then thrown back upon the only other element in the arc, that is, the brain center. We have reason to believe that the sensation is what it is in consequence of the brain center through which the nervous impulse is conducted. We experience sight sensations, not primarily because we have eyes, but because impulses are transmitted through the sight centers in the occipital lobe. We experience sound sensations because impulses traverse the combinations of cells in the center for hearing. It makes no difference by what means or in what organs the impulses are established, if they go through the sight center, we experience the sensation of sight.

Eye and Ear Interchanged.—Occasionally we read in newspapers that some celebrated surgeon a long ways off, either as the result of a blunder or for the purpose of experiment, has misplaced the connection between the auditory and the optic nerve, so that the ear is connected with the proximal end of the optic nerve, and the eye with the proximal end of the auditory nerve. Then the patient sees with his ears and hears with his eyes. We need not concern ourselves with the possibility or impos-

sibility of such an event ever occurring, for it would be about as reasonable to suppose that the same celebrated surgeon had misplaced the connection between a man's leg and his head, so that the leg, cut off at the knee, was made to grow on the stump of the neck, and the head was placed so that it grew where the knee was formerly attached. But we may merely assert that if anything ever happened that way that is just the way it would happen. But if the auditory nerve were so connected that the impulses established in the ear were transmitted through the sight center, and the impulses established in the eye were carried to the hearing center, then we should see music and hear a picture.

Different Sensations From Same Sense Organ.—We have no difficulty in discriminating sensations as qualitatively different when they are the accompaniments of impulses established in different sense organs; but we may experience sensations qualitatively different when the concomitant impulses are established in the same sense organ. The sensation of sweet is qualitatively different from the sensation of bitter; and the sensation of red is different from the sensation of blue. The explanation must be the same. The combination of brain cells traversed by an impulse when we experience the sensation red, is a different combination from that which is traversed when we experience the sensation blue, although both combinations are found in the occipital lobe. Not only are the combinations different, but no single cell that is found in one combination occurs in the other. This is the final test by which we may judge

whether one sensation is qualitatively distinct from another or not.

The Synaptic Process.—Our discussion of sensation will not be complete unless we go one step farther in locating the point at which the concomitant physiological process occurs. We have gradually narrowed the field of our investigations from the brain, through the cerebrum, hemispheres, cortex, neurons, and now it is possible to go one step farther and assert that the physiological change which accompanies a sensation, as well as every other mental process, occurs at the tips of the dendrites; or just at the point where the nervous impulse passes from one neuron or brain cell over to another. This point where the dendrite of one cell and the axon of another most nearly approximate each other is called the synapse, and the physiological concomitant of a mental process is a synaptic function. It is not a function of the cell, nor is it associated with cell structure; but it is a systematic function, a dynamic effect, and depends upon the transmission of the impulse from cell to cell. We see then how inaccurate are the expressions that assert that ideas are stored away in cells; or that the brain retains impressions and many other expressions of a similar nature.

Quantitative Difference.—Besides the qualitative difference, sensations differ in another respect. They may be of the same kind, but differ in intensity. We may call this a quantitative difference and say that sensations are strong or weak. Adjectives are not merely qualitative, but qualifying adjectives may be compared. Quali-

fying adjectives express qualitative differences in sensations, but comparison of adjectives expresses a quantitative difference. Thus we have sweet, sweeter, sweetest; cold, colder, coldest; brave, braver, bravest.

Depends Upon Intensity of the Stimulus.—We need have no hesitation in saying that the intensity of the sensation depends upon the intensity of the stimulus; but it would be a wrong conclusion to infer that an increase in the stimulus would cause an equal or similar increase in the sensation. Doubling the stimulus does not double the intensity of the sensation.

Example of Light.—The determination of the law that governs the relation between the increase of stimulus and the increase in sensation is difficult. We may see to read in a faint light, but doubling the amount of light does not enable us to see to read twice as well. So it is a very gross exaggeration to say on a fine moonlight night that it is as light as day. It can be shown that if the entire sky were covered with full moons, each as bright as the one we see, and the amount of light increased 10,000 times, it would still be not even one-eighth as bright as day. But the ability to see by moonlight is much greater than one ten-thousandth, or one eighty-thousandth of what it is by day.

Example of Weight.—If I hold a weight of 100 grams in my hand, it will be necessary to add to this weight five grams before I can discover that there is any increase in sensation, or that the weight has become heavier. If I hold a weight of 20 grams in my hand, a weight of one

gram added to it will be perceived as heavier. But if I hold a weight of 1,000 grams in my hand, an additional weight of neither one gram nor five grams will be perceived as making an increase in the intensity of the sensation. An additional weight of 50 grams must be placed with the 1,000 grams in order for the sensation to be appreciably increased.

Least Perceptible Difference.—This method of studying the increase in intensity of sensation is known as the method of least perceptible difference. It is not the absolute increase in the stimulus that produces equal increases in sensation, but the relative increase. In the illustration above, unequal amounts of stimulus produced equal amounts of sensation; but it will be observed in each case that the same proportion of weight was added to the amounts already supported. In this case, one gram, five grams and 50 grams increase in weight produced equal increase in sensation; but in each case the proportion of the weight that was added to the amount already supported was one-twentieth.

Threshold of Difference.—In the same way it has been determined that the intensity of light must be increased or decreased by one one-hundredth of the amount before any difference in brightness, or intensity of sensation, can be perceived. The fraction representing the proportion by which the stimulus must be increased or decreased before any change in the intensity of the sensation can be perceived is called the threshold of difference. The threshold of difference for sight is one one-hundredth; for weight, one-twentieth; for strain, one-for-

tieth; for hearing, one-third; for taste or smell, about one-third.

Weber's Law.—The statement of the relation between the stimulus and the sensation is known as Weber's law. It may be stated in three different ways. First, in order that the sensation may increase by quantities always equal, the stimulus must increase by a constant fraction of itself. Second, in order that the sensation may increase in arithmetical progression, by the addition of a common difference, the stimulus must increase in geometrical progression, by a constant multiplier. Third, the sensation varies as the logarithm of the stimulus.

Explanation of Weber's Law.—The explanation of Weber's law is not easy, but the quotation from James at the beginning of this chapter is very suggestive. If we adopt the view of the nature of the nervous impulse outlined in Chapter IV, we shall be helped much toward an understanding of it. Let us suppose that the transference of an equal number of atoms from one molecule to another is the concomitant of equal increases in sensation. But in order that there shall be equal increases in the number of atoms transferred, there must be a much greater force applied in establishing the impulse.

Illustration.—Let us suppose that there is a plum tree approaching the time when the plums are ripening. If we give the tree a slight shake, some plums will fall. But in order to make an equal number of plums fall at the next shaking, we must increase the force applied. At the third shaking, the force must be tremendously in-

creased if we wish to make an equal number of plums fall. This seems to be a fair illustration of what probably occurs in the establishing of an impulse.

DEFINITIONS.

Sensation—A simple mental process that makes us acquainted with a quality of an object and which is accompanied by a peripherally initiated impulse.

Quality—That in an object which corresponds to a sensation.

Peripherally Intiated Impulse—One which starts in a sense organ.

Centrally Initiated Impulse—One which originates in a brain center.

Qualitative Difference—A difference in kind. One which is indicated by a different name.

Quantitative Difference—A difference in intensity, not in kind.

Qualifying Adjective—The name of a sensation.

Weber's Law—A statement of the relation between an increase in the intensity of the sensation and the quantity of stimulus.

Threshold of Difference—The fraction by which the stimulus must be increased before an increase in intensity of sensation can be perceived.

Synapse—The point of nearest approach of two neurons, and at which the transfer of the nervous impulse from one brain cell to another occurs.

CHAPTER X

PERCEPTION.

The task of the psychologist is to reduce every mental process to a neural process; every conception to perceptions, grouped and abstracted, as perceptions are sensations grouped and abstracted.—*Lewes, Problems of Life and Mind, First Series, Volume II, p. 199.*

Perception seems to involve in every case a synthesis of sensations and images of different senses, and the synthesis results in an establishment of relations of some kind among the sensations.—*McDougall, Physiological Psychology, p. 94.*

Two nerve centers stimulated at the same time secure a connecting path of least resistance by which, in future, the stimulation of the one overflows into the other.—*Munsterberg, Psychology and the Teacher, p. 142.*

It has been assumed that when two groups of cells, the substratum of two images, are excited at the same time, the nervous wave circulates from one group to the other through those communicating fibers which are so numerous in the brain.—*Binet, Psychology of Reasoning, p. 185.*

This might be called, for reasons that we shall consider presently, the law of the Attraction of the Impulse.—*McDougall, Physiological Psychology, p. 126.*

Ideas in their simplest form are reproduced, or recalled sensations.—*Hoffding, Psychology, p. 141.*

We seem to be justified in calling the elements of both memory image and perception, sensations.—*Pillsbury, Attention, p. 95.*

Perception.—Sensation is a simple, while perception is a complex, mental process. In other respects they are much alike, and as would be supposed, the two processes shade into each other. Let us study the process of perception as it is exemplified in the perception of an apple.

Exemplified in An Apple.—When I hold an apple in

my hand and look at it, I experience several sensations. I experience a sensation of red, which informs me of one quality of the apple. I experience a sensation of green, since the apple is not red throughout its entire surface. I experience another sensation through the sense of sight, by means of which I judge of its size, and another sensation, also through the sense of sight, by means of which I judge its distance; and still another from which I judge its shape. I experience a sensation through the skin that informs me of its smoothness, and another that tells me it is cold. Still another sensation is obtained through the muscular sense which informs me of its weight, and possibly the sensations of strain and pressure enter into the same judgment.

Vivid Sensations Combine.—An enumeration of the sensations already indicated as experienced shows that we have appreciated at least eight, each of which is accompanied by a peripherally initiated impulse, and which in consequence of that fact we may call vivid sensations. They are all experienced at the same time, and they run together and modify each other. The resulting combination of all the sensations, as they modify each other, constitutes the percept.

Pure Percept.—If these sensations already described were the only sensations that entered into it, we should have a pure percept. We might define a pure percept, then, as the sum of all the vivid sensations that we get from an object, as they combine and modify each other.

But a pure percept is seldom or never experienced. It is one of those philosophical abstractions, convenient to

contemplate as the basis of theoretical discussion, but never realized in practice, unless it be in the very first perceptions that we ever experience.

Faint Sensations.—As soon as we have begun to experience the vivid sensations from an apple, through the senses of sight, touch, temperature and pressure, other sensations begin to appear. We begin to experience a sensation of taste, and perhaps our mouth begins to water. We experience a sensation of sour or sweet; we experience a sensation from which we judge that the apple is mellow, also that it is white inside, is juicy, and has a core and seeds.

Their Origin.—These sensations are derived from previous experience with apples. They are reproduced sensations, accompanied by centrally initiated impulses, and are consequently of that kind that we may call faint. It would really be better if we had some other word than sensation to apply to them, but as we have none, we shall continue to distinguish faint sensations from vivid; the difference being that vivid sensations are accompanied by peripherally initiated impulses, while the faint sensations are accompanied by centrally initiated.

Definition of a Percept.—All the sensations, both faint and vivid, run together, modify each other, and the resulting experience is called a simple percept. It is the kind of a percept we mean when we use the term without any modifying word. We may define a simple percept, then, as the sum of all the sensations, both faint and vivid, that we get from an object, as they modify each other.

What We Perceive.—We have described the sensation as a process that makes us know the quality of an object, and the percept contains no elements except sensations. It would appear, then, that the only thing that we can know about an object is the sum of its qualities, or such qualities of the object as our sensations are able to acquaint us with. Is there anything in the constitution of an object except its qualities? Are we compelled to define an object as the sum of its qualities, and fail to discover that there is anything else in the constitution of an object except qualities?

Idealism.—It is only a step from this position to the demonstration that there is no object nor external world. If we know only qualities, and know them only as they are correspondences to sensations, then we know really only sensations. The object, then, is only the collection of correspondences, and the only thing that we can be sure about is the mental experiences that we call our sensations. Hence if there were no sensations, and no mental processes, and no person to experience them, there would be no correspondence and no object and no etxernal world. The world external to ourselves is merely a construct of our minds.

Transfigured Realism.—Persons who hold such opinions as are expressed in the preceding paragraph are called idealists. Persons who believe that the object is some real thing other than the sum of its qualities, and that we know the qualities by means of our sensations, are called realists. Herbert Spencer argued

that while we could know nothing about an object except its qualities, nevertheless the fact that there were qualities that we could perceive implied that there must be a thing in itself to which the qualities belonged. He argued that there must be a substantial thing in itself to serve as a substratum for the quality, since a quality could not exist alone. A quality without a substantial substratum would be like the smile of the Cheshire cat, in Alice in Wonderland. The Cheshire cat was sitting on the branch of a tree, smiling as all well regulated Cheshire cats do, when the tree and the branch and the cat gradually faded away, leaving only the smile out in space. What would the smile of a cat look like without the cat behind it?

Hence, Herbert Spencer asserted that the existence of a quality which we could know implied positively the existence of a real thing which we could not know. He called this the doctrine of Transfigured Realism.

Percept Not the Arithmetical Sum.—But the percept is not merely the arithmetical sum of the sensations that we derive from an object. It is the sum of the sensations as they modify each other.

Sensations Modify Each Other.—This modification of sensations by each other when they are experienced together is one of the most important principles in the understanding of the process of perception. We have already had occasion to refer to the fact in our discussion of the relations between taste and smell on page 86. That two or more sensations experienced at the same time modify each other is shown in many ways. The phe-

nomenon of contrast represents it very well. Black always looks blacker when it is experienced in contrast with white. Red is redder when it is shown on a background of green. Sweet and sour emphasize each other.

Example of Lemonade.—Lemonade is made by mixing together lemon juice, which produces the sensation of sour; sugar, which gives us the sweet taste; a few drops of lemon oil, which is bitter; ice, which arouses the sensation of cold; water, which gives a touch sensation, and occasionally a pink color, which appeals to the eye. But neither of these ingredients arouses the lemonade taste, or gives us the lemonade sensation. In fact, in lemonade, and better, in some other mixtures, it is very difficult, or almost impossible, to analyze out of the compound the sensational elements of which it is composed.

If the sensations that enter into the composition of the lemonade taste were to be experienced at different times, they would certainly not produce the lemonade taste. But even if the several ingredients were tasted at the same time in different portions of the mouth, the resulting percept would not be the same as if the ingredients were more intimately blended.

Of Contrasting Colors.—Red, yellow and green are all of them beautiful colors; but if combined conspicuously in a lady's dress, we say that the colors fight; they modify each other in an unpleasant manner. Salt is not in itself a very pleasant taste, but there is no other article of table use that appears in so many different articles

of food. The little boy's definition of salt as that which makes potatoes taste bad when you do not put any on, emphasizes its function. Salt is especially powerful in modifying sensations of taste in such a manner as to intensify them.

Of Food.—We like to eat our dinner where the dishes and linen are clean. Dirty dishes and dirty table linen modify the taste of the food in an unpleasant manner. So beautiful tableware, china and silver contribute much to the enjoyment of eating dinner. Music intensifies the pleasant taste of food.

Law of the Attraction of the Impulse.—The physiological concomitant of the modification of one sensation by another seems to be found in the fact that when two nervous impulses are established at the same time, they tend to run together and modify each other. The two or more impulses may run together in such a manner that the single impulse resulting is stronger than either of the two of which it is composed, or they may combine in such a way that they tend to diminish or nullify each other. In the one case, the accompanying sensations are intensified, while in the other they are diminished. The fact that two impulses established at the same time tend to combine is called by Mr. McDougall the Law of the Attraction of the Impulse.

Completed Definition.—The percept, then, is the sum of all the sensations, both faint and vivid, that we receive from an object, as they modify each other. Since the sensations are experienced at the same time they are held together by that form of association that is called

simultaneous association. Here it may be well to consider another phenomenon of sensation and perception, which tends to verify the accuracy of the interpretation here laid down, and which at the same time may be explained by it. This is the phenomenon of colored audition, or colored hearing, or chromoaesthesia.

Colored Audition.—Some persons experience a sensation of color when they hear certain letters, or words. Each word or letter seems to have its own color, but the color is not necessarily the same for any two persons. Dr. David Starr Jordan asserts that the different letters of the alphabet have for him different color values, so that he always experiences the different color sensations whenever he hears the sounds of the letters. X, Z, F, E, H, A, N are always red. L, T, B, R are green. O is yellow. Names of persons, days of the week and months of the year have different color values for different persons. In a very few instances, other sensations than color and hearing are associated. In one case a distinct sensation of temperature was associated with the sound of words, and in another that has been reported color was experienced in connection with different tastes.

How Account for It?—We may suppose in case of colored hearing that when the letter O, for example, in President Jordan's case, is heard, the nervous impulse established in the hearing center is transmitted over into the color center, and passes through the combination of cells that is associated with the color sensation. This pathway between the hearing and the color center has probably been rendered easy of access in consequence of

early association. In President Jordan's case, the letters may have been learned originally from colored blocks, and the two centers for sight and hearing became thoroughly associated in that way.

Its Bearing Upon the Theory of Perception.—The significance of the phenomenon of colored hearing for the the theory of perception depends upon the fact that it shows that different brain centers are traversed by the same nervous impulse, and by inference, that different sensations are associated in the perceptive process.

What a Brain Center Is.—We are now ready to understand that there must be much modification of our original theory of the localization of function. We defined a brain center in such a way that it would be supposed to consist of a number of brain cells in close proximity to each other. But in the perception of an apple, we have reason to believe that many different brain centers, in several regions of the brain, come to be associated and are traversed by the same nervous impulse. These several combinations of brain cells in different sensation areas may be widely separated; but since they are traversed by the same nervous impulse, they constitute in effect a single brain center. Hence, we shall need to define a brain center as a combination of cells traversed by the same nervous impulse. It is the impulse itself that defines and delimits the brain center, and not mere geographical proximity. This adds enormously to the difficulty of making a thoroughly satisfactory demonstration of the truth of the doctrine of localization of function.

Assimilation and Apperception.—As soon as we have obtained a simple percept of an apple, other ideas begin to rise up in the mind. We no sooner think of the apple than there begin to appear other related ideas: tree, orchard, cider, apple pie, Garden of Eden, worm, scale insects, seedlings, grafts and many other ideas, depending for their number and particular kinds upon our previous experience. These related ideas associate themselves with our simple percept, and the result is what we may call an assimilation. The process by which an assimilation is formed we may call apperception. An assimilation, then, is the sum of the simple percept together with all of its related ideas. It may be well to notice that the word apperception, as here used, has a somewhat different signification from the Herbartian sense of the word, and indeed is different from the use that is made of it by Wundt.

Distinguishing Characteristic of a Percept.—A percept must always involve some sensations that are accompanied by peripherally initiated impulses. That is, in every percept there must be some vivid sensations. In nearly every case, at least, there are also faint sensations, but the vivid sensations must occur if we are to call the resulting process a percept.

An Idea.—When we experience a process in which all the sensations are faint, accompanied by only centrally initiated impulses, the process is not a percept but an idea. An idea may be defined as a remembered percept, or a percept without vivid sensations, or a process in which faint sensations only are combined.

Idea and Faint Sensation.—It is better to reserve the word idea for this use than to employ it as some psychologists do, to express a faint sensation. It would conduce to clearness if we had some other word than sensation to express the notion of a simple mental process that is accompanied by a centrally initiated impulse only. But as it is, we have no such word, so we may discriminate faint and vivid sensations by means of their accompanying centrally and peripherally initiated impulses.

Difference Between Idea and Percept.—A percept differs from an idea primarily in its vividness. The percept is vivid, the idea is faint. If an idea were to become as vivid as a percept, we should then experience an hallucination. The percept is accompanied by some peripherally initiated impulses, the idea by no peripherally initiated impulses. A percept is usually more accurate than an idea, largely in consequence of its greater vividness.

Association Centers.—In this explanation of the difference between a percept and an idea, it has been assumed that both centrally initiated and peripherally initiated impulses traverse the same combination of brain cells in the percept and idea of the same thing, and that this combination includes cells in both cases that belong to different sensation centers. Those who hold positively to the doctrine announced by Flechsig concerning his association centers, will postulate another difference between idea and percept. They will assert that in a percept the impulses traverse sensation centers, but that in an idea, impulses traverse association centers

only, none passing through the cells in the sense areas. It seems very unlikely that such an hypothesis can be substantiated, and the weight of the evidence is strongly against such a notion.

DEFINITIONS.

Percept—The sum of all the sensations, both faint and vivid, that we get from an object as they modify each other.

Pure Percept—The sum of the vivid sensations only that we get from an object.

Perception—The process by which a percept is formed.

Assimilation—The sum of the simple percept, together with all the related ideas.

Apperception—The process by which an assimilation is formed.

Simple Percept—See percept.

Idea—The sum of faint sensations only. A remembered or reproduced percept.

Chromoaesthesia—Colored hearing—colored audition. A phenomenon in which sensations of color are aroused by auditory sensations.

Transfigured Realism—The doctrine that there is a real object to which the qualities belong, although we are able to know only the qualities and not the thing in itself.

Law of the Attraction of the Impulse.—A statement of the fact that when two impulses are established at the same time they tend to run together and consitute a single impulse.

Brain Center—A combination of brain cells traversed by the same impulse.

CHAPTER XI

HALLUCINATIONS AND ILLUSIONS.

By illusion is meant a subjective interpretation of an objective impression.—*Hoffding, Psychology, p. 145.*

It is only in special cases that centrally excited sensations can rise from their accustomed faintness to the vividness of sense perceptions. We then speak of them as hallucinations.—*Kulpe, Psychology, p. 186.*

Several trustworthy observers have stated that they are able to call up at will visual sensations of definite quality and of equal vividness with those of external perceptions. These visual qualities are, as a rule, quite clearly distinguishable from ordinary memorial images, and as in extreme cases they have been found to give rise to after images, there can be absolutely no doubt that the peripheral organs are concerned in their production.—*Kulpe, p. 434-5.*

Hallucination.—Hallucinations and illusions are both of them errors in perception, and no discussion of the perceptive process can be satisfactory that does not indicate how the theory of perception may explain them. We have seen that a sensation is the concomitant of a peripherally initiated impulse. A percept is the sum of sensations, some of which are accompanied by peripherally initiated impulses. An idea is a somewhat similar process, except that the sensations that enter into it are all faint and accompanied by centrally initiated impulses only. The peripherally initiated impulse is always stronger than the centrally initiated, and the accompanying sensations are more vivid. It is by means of the vividness of the processes that we are able to distinguish a percept from an idea. When, however, it happens, as

it sometimes does, that the centrally initiated impulse becomes unusually strong,—as strong as a peripherally initiated impulse would be under the same circumstances,—we are unable to distinguish the centrally initiated impulse and its accompanying idea, from a peripherally initiated impulse and its accompanying percept. When we lose this characteristic vividness of distinction, we experience an hallucination. An hallucination, then, is an idea so vivid that we mistake it for a percept.

Occur When Vivid Percepts Impossible.—Hallucinations usually occur when the conditions for perception are not very good. We are more likely to see ghosts in the dark, or dim light. The usual explanation of this fact is that the material of the ghost's body is so extremely tenuous that it is unable to withstand the disintegrating action of light. While this explanation would perhaps not be very satisfactory except to an extremely credulous ghost seer, it does illustrate the fact that hallucinations are likely to occur when the conditions for perception are somewhat unfavorable.

And When Attention Is Weak.—Still another condition favorable for hallucinations is that in which the attention is wandering. Hallucinations are sometimes experienced just when we are going to sleep, or just waking up, or in a condition of day dreaming, or revery. It is a condition in which a percept would not likely be very vivid, while the idea is likely to become so. The person who reports an hallucination frequently emphasizes the fact that he was perfectly placid, not in the least excited, and adduces this condition as evidence that

he is not likely to be mistaken in his perception and that the appearance was not hallucinatory. This placid condition is one that is quite necessary for the most common type of hallucination.

Not Uncommon.—Hallucinations are not at all uncommon. A census of hallucinations shows that about one person in ten has at some time in his life experienced a true hallucination. The actual number is probably much greater than this, in consequence of the tendency to be forgotten, as well as the disinclination of many persons to report such an experience. The probability is very great that every person has experienced one or more hallucinations, but in much the larger number of cases they have not been recognized as hallucinatory.

Most Frequent in Young Persons.—The investigations into hallucinations indicate that the largest number occur to persons between the ages of 20 and 25 and the number diminishes as the persons become older. The probability is strong, however, that the younger the persons are, the greater the number of hallucinations they experience. In all probability, little children experience a large number of hallucinations, but they are not recognized by the children nor by their older associates as hallucinatory, and children have no way of describing their experiences of this nature, even if they were recognized. The intensity of nervous energy, such as little children manifest, is one of the contributory conditions of hallucinations.

Children's Lies.—Some of the lies that children tell

may be accounted for by supposing that the children experience ideas so vivid that they are unable to distinguish them from a percept, and report as seen or heard or done things that were not seen or heard or done.

Hallucinations of the Dead.—Hallucinations frequently take the form of a vision of some one with whom the person is acquainted, but who has recently died or who dies soon afterward, or who is sick and in danger of death. Consequently it has been supposed that there is a very intimate connection, not to say prophetic relation, between appearances of an hallucinatory character and the fact of death.

Naturally Accounted For.—When hallucinations associated with the fact of death occur, we may account for them in a very natural manner. First, the visual appearance of a person who is dead is more likely to be recognized as hallucinatory than an appearance of any other character. Hence it is more likely to be reported in a census of hallucinations than is any other kind.

Better Remembered.—Second, such an hallucination, from the fact of its being associated with the death of a person, is likely to be remembered better than one in which no such connection can be traced, and is on this account more likely to be reported. The ordinary hallucination, like a dream, is very likely to be forgotten, or remembered with difficulty. This in itself implies a nervous impulse of little strength, and the vividness is more apparent than real.

Other Reasons.—Third, the person who has recently

died or who is sick and in danger of death, is more likely to be in the unconscious thoughts of a percipient than another person who is in no such immediate danger of dying. Fourth, there is not much similarity between the hallucinations of the dead and dying, so that no relations between the forms that the hallucinations take can be traced. This in itself is sufficient to show that there is no real connection between hallucinations of this character and the fact of death. Fifth, a few such coincidences are nearly sure to occur according to the law of probabilities. Many more hallucinations, however, occur that are not connected in any way with the death of the person perceived than are so connected.

Historical Visions Hallucinations.—The probability is that all accounts in history of visions and angels and warnings and foreshadowings of death, and other mysterious appearances, when not intentional deceptions, are to be explained on the principle of hallucinations. Such will be found to be the explanation of the familiar demon of Socrates, who gave him warnings; of Joan of Arc, with her voices; of Mohammed, and the thousands of appearances of angels and devils to saints and ascetics.

Mostly of Sight and Hearing.—Hallucinations occur most frequently in the senses of sight and hearing, but they may occur in any sense. Hallucinations of touch are not uncommon, while hallucinations of taste and smell have been experienced. A person who is subject to hallucinations is likely to become a veritable mine of ghost stories, while the real explanation is a very simple one.

Hallucinations of the Insane.—Insane persons are especially subject to hallucinations, if the insanity is of that kind which runs into maniacal forms, characterized by ravings and violence and much inflammation of brain tissue. A man in delirium tremens experiences the most prodigious forms of hallucinations. If, however, the insanity takes the form of melancholia, associated with a degeneration of brain tissue, and the loss of ability to generate nervous energy in the usual amount, hallucinations are seldom or never experienced. Frequently the hallucination is one of the first symptoms of oncoming insanity, although many persons experience hallucinations who can not be suspected of insanity in any degree. Whenever the centrally initiated impulses come to have an exaggerated intensity, which may or may not arise from a diseased condition of the brain, the result is a vividness of ideas that constitutes an hallucination.

Illusions.—But we frequently experience errors in perception that are not hallucinations. It is probable that every one of us has sometime gone down the street in the semi-darkness of the evening and has seen a friend standing at the side of the walk. As we approached ready to speak to him we discovered that instead of its being our friend it was a gatespost. Our friend may have been just as wooden headed as the gatepost, but that was not the point of resemblance which induced the mistake. Or we may have gone into our room when it was poorly lighted and found some one sitting in a chair, who, upon investigation, proved to be merely a cloak or shawl thrown over the chair and not a person.

Explanation.—Such experiences are illusions, not hallucinations. There is something there to see. A peripherally initiated impulse is established, but it is carried to the wrong center. The peripherally initiated impulse established by the gatepost went to the friend center instead of the gatepost center.

Miscalling Words.—The same explanation enables us to understand why we miscall words, or read them wrong. A child in the reading class called the word irrecoverable, irrevocable. The impulse that was established by the sight of the word went to the wrong center, and traversed the wrong combination of cells.

Two Sources of Error.—There are two explanations for illusions of this kind, or two sources of error. The first is that the nervous impulse is directed by a process of attention, and if we attend in the proper way, we shall direct the nervous impulse into almost any brain center that we wish. This is sometimes stated by saying that we see what we expect to see. Expectation is merely another name for a process of attention in a case like this, and is a very prolific source of illusion. If our attention is very perfect, we shall be able to see almost anything.

Hypnotic Illusions.—We shall find that the most satisfactory explanation of the phenomena of hypnotism is one that depends upon the fact that the hypnotic state is that of almost perfect attention. One of the most striking phenomena of hypnotism is that in which the hypnotized subject is induced to see almost any object that is sug-

gested to him, in any place. This is an illusion depending upon the process of attention.

Illusions from Habit.—The other explanation is one in which the impulse is directed into the pathway established by habit. We see the thing that we are accustomed to see, and fail to see the new and unusual. The effect of the transmission of a nervous impulse through a nervous arc is to diminish the resistance the impulse encounters, for every transmission. The statement of this fact is called the law of neural habit.

The Law of Neural Habit.—The law of neural habit is such an important principle in psychology, and underlies the explanation of so many psychological phenomena, that we need to get a clear understanding of it. No fact in physiological psychology is better known or more fully recognized than that whenever a nervous impulse traverses a nervous arc, it modifies the arc in such a manner that the next impulse of the same degree of intensity will encounter less resistance. As the result of repetition, the arc ultimately furnishes so little resistance to the impulse that practically none of it is lost in transmission.

Inaccurate Expressions.—This principle is the only valid interpretation of the phenomena that are sometimes inaccurately described by saying that every mental action leaves some trace in the mind; that the mind retains a trace of every impression made on it; that ideas are stored up in the mind; and others of that nature.

Importance of the Law of Neural Habit.—It is the law of neural habit that lies at the basis of every explana-

tion of mental or physical habit, and the economy of effort that arises from it. Also, we shall find that this law of neural habit explains the decrease of feeling in habitual experiences, lies at the foundation of the development of unconscious voluntary action, controls the growth of secondary passive attention, and is the source of many common forms of illusion.

A Third Principle.—These two principles are sufficient to explain almost every illusion that we experience. However, it may be profitable to postulate a third principle. If we have two lines of equal length terminating in forks, but the forks of one of them extending away from the middle of the line, while the forks of the

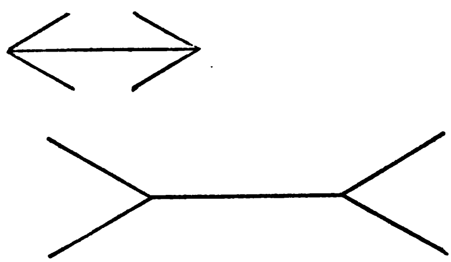


Fig. 26—Two lines of equal length that do not appear to be so.

other extend back toward the middle, the first line will appear the longer. This is an illustration of a very numerous class of illusions, the error in perception seeming to arise from the influence or effect of surrounding circumstances. Although this may be classed as an independent principle, it is capable of reduction to the law of neural habit.

Examples of Illusions.—As another example of this

class of illusions, we may suggest the well known one of two heavy, parallel lines, with additional lines radiating from a point between them. The straight vertical lines will appear to be curved. Or, if we draw a circle, and then from a point without the circle draw lines that shall

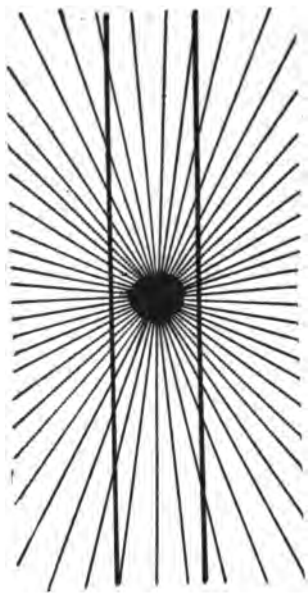


Fig. 27—Illusion of the curved lines.

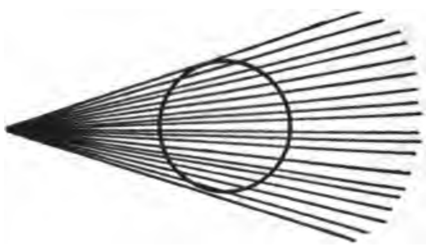


Fig. 28—Illusion of the flattened circle.

spread out fan-shaped over the circle, the circle will appear to be flattened. It appears that this error in perception arises as the result of our experience with forces acting upon similar objects. It may well be questioned whether a little child under the same circumstances would not see the circle exactly round, and the lines exactly parallel.

The Stairway Illusion.—If we look at the outline drawing of a stairway, we shall probably see it as the upper side of the steps at first; but by the proper kind of attention, we shall be able to see it as the under side. We can by an act of attention see it either way. It is

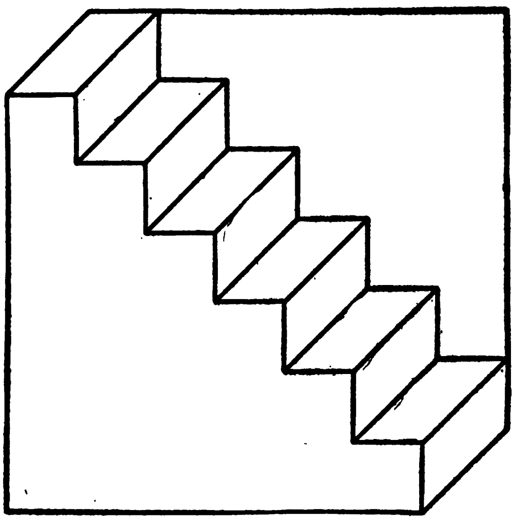


Fig. 29—The Stairway Illusion.

probable that the upper side will appear to us at first, because we are likely to be more familiar with the ap-

pearance of the upper side of stair steps than with the lower. If we have never seen the lower side of the steps of a stairway, it will be impossible to see them in the drawing.

The Duck and Rabbit.—Similiarly, we may see in the same picture, either a duck's head or the head of rabbit; and by a process of attention, we may see either at

a

Fig. 30—The Duck and Rabbit Illusion.

will. But if we have been familiar with the appearance of a rabbit's head, and have never seen the head of a duck, the duck's head will not appear to us.

The Windmill.—If we watch a whirling windmill from a position about 45 degrees to one side of the direction of the axis, and from a distance of a hundred or two hundred yards, we shall by a process of attention, be able to see it turning in either direction.

Puzzle Pictures.—A puzzle picture is a negative illusion. In an illusion we see what we expect to see, as the result of habit and attention. But in a puzzle picture we do not know what the thing we are searching for will look like, so we are unable to direct the impulse by a

process of attention. Hence, instead of seeing what we expect to see, or seeing what we attend to, we know not

Fig. 31—Puzzle Picture: "Come and swing me, Harry." Where is Harry?

what to expect, and are unable to attend; consequently we fail to see what is in the picture to be discovered.

Bearing upon Theory of Perception.—Hallucinations and illusions are anomalies of perception, which help us to understand the process better than we should be able to do without an explanation of them. A consistent

explanation of hallucinations and illusions can be made understandable only by some hypothesis of the course of a nervous impulse. To say that the mind reacts in its customary way; or that consciousness interprets an appearance so and so, as is commonly done, would be verbally intelligible, but would really mean nothing, and is incapable of being translated into intelligible terms. By examining the physiological process involved in an illusion, we are led to an understanding of the complete perceptive process.

DEFINITIONS.

Hallucination.—An idea that is as vivid as a percept, and which is mistaken for it.

Illusion.—The concomitant of a peripherally initiated impulse which is carried to the wrong brain center.

Law of Neural Habit.—A statement of the fact that the transmission of an impulse through a brain center modifies the brain center in such a way that succeeding impulses encounter less resistance.

CHAPTER XII

THE PERCEPTION OF TIME AND SPACE.

Space is the abstract of coexistent positions.—*Lewes, Problems of Life and Mind, First Series, Volume II, p. 486.*

The retina has no power of perceiving relations of contiguity or position among its parts. This perception is due to the movement of the muscles of the eye.—*Ribot, German Psychology, p. 121.*

When the moon is high above our heads, we have no means of estimating its distance from us, since there are no intervening objects with which we may compare it. Hence we judge it to be nearer than when, seen on the horizon, it is farther off than all terrestrial objects. Since the size of the retinal image is the same in the two cases, we reconcile the sensation with its apparent greater distance when seen on the horizon, by attributing to the moon in this position, a greater actual size.—*Am. Txt. Bk., Volume II, p. 355.*

Even in ourselves the respiratory intervals, joined sometimes with the intervals between the heart's pulses, furnish part of the materials from which the consciousness of duration is derived.—*Spencer, Psychology, Volume I, p. 215.*

Intuitive Ideas.—It was formerly believed that space and time are intuitive ideas. By this it was meant that the ideas of space and time are furnished by the mind itself, and are not derived in any way from experience. They have been called necessary forms of thought, and it has been denied that experience enters in any way into the acquisition of these ideas.

No Space Perceiving Sense.—We have no particular sense for the perception of space. In fact, we cannot perceive space at all, but we may perceive distance. By distance, we mean the relation that exists between two coexistent positions. We perceive the distance between

two objects, or between two points on the same object.

Derived From Perception of Distance.—Space is an abstraction derived from a comparison and perception of resemblance between all of our perceptions of distance. Our senses are not all equally efficient in affording us a measure of distance. Smell does not furnish us an idea of distance; neither does taste, nor equilibrium, although Mr. James asserts that all of our sensations have a spacial character.

Muscular Sense the Fundamental Sense in Perceiving Distance.—Hearing gives us some information about the distance that a sounding body is from us, but not a great deal. The primary sense upon which all of our perceptions of distance must ultimately depend is the muscular sense. This sense is often combined in the perception of distance with the sense of touch, but not always nor necessarily so. We decide, by the amount of muscular effort required to move our hand from one place to another, how far the distance is. Our finger may be on one point and we may move it to another. The touch of the finger serves to delimit the distance, indicating the two ends of the line that measures it, but it is not necessary that we should touch anything in order to judge of distance. I may move my hand through the air without touching anything whatever, and I may judge merely by the amount of muscular effort involved in the moving, how much distance the finger has moved through. I know very well whether I have moved it through a short distance or a longer one. So it is really the muscular

sense, and not the sense of touch, that enables us to judge of the extent of the distance.

Even in Long Distances.—Even in greater distances than can be reached by the length of the arm, we judge by means of the muscular sense. We judge of the distance between two places in town by means of the muscular effort expended in walking from one place to the other. One road seems to be a very long one if we have expended much muscular effort in traversing the distance, while another appears to be shorter if it has required less effort to pass over it. It is the muscular effort in every case that furnishes us our fundamental notion of difference in position which we call distance.

Perceived by the Eye.—As soon, however, as we have learned through the muscular sense to judge of distance, we begin to interpret the appearance of distance with the eye, and this immensely extends the distances we are capable of observing. Even here, however, it is the muscular sense that enables us to judge of distance. When we wish to look at an object that is very small we hold it about ten inches from our eyes. This is regarded by all microscopists and opticians as about the distance at which the normal eye can see the smallest possible object of which it is capable. In order to look at an object with both eyes at a distance of ten inches, we must exert some muscular force to turn the axes of the two eyes to the same point. It requires considerable effort to turn them to a point closer than ten inches, as every one may discover by following the end of his

finger toward his nose until his eyes turn inward and he looks cross-eyed.

Muscular Sensations in Eye Movements.—When we look at an object twenty inches away, we need to turn the eyes toward the object, and the lines that run from the object to the two eyes make a different angle from that which they made when looking at it from a distance of ten inches. This difference in the amount of muscular effort exerted, and in the intensity of the muscular sensation experienced, enables us to judge that the second object is farther away than the first object was. So we may make a fairly accurate judgment of the distance of an object by means of the muscular sensation established in the rectus muscles of the eye, until the line connecting the two eyes, and constituting the base of the triangle becomes very small compared with the sides of the triangle.

How Judge Distance with One Eye.—A man who has only one eye can judge of distance, although not so accurately as can a man with two eyes. He judges the distance by means of the muscular sensation established, not in the rectus muscles that move the eyeballs, but the ciliary muscle by which the shape of the crystalline lens is altered.

When we look at an object that is near, the crystalline lens must be relatively convex in order to bring the rays of light to a focus on the retina. When we look at an object farther away, the lens needs to be flatter. This flattening of the lens is accomplished by a

contraction of the ciliary muscles. The farther away the object is, the more tension must be exerted upon the ciliary muscles, so that by the greater or less intensity of the muscular sensation accompanying the impulse, we judge that the distance is much or little. If the other explanation of the action of the muscles in flattening the lens should prove to be the true one (see page 5-5), the judgment of distance remains the same. A man with one eye has only one of these methods of judging distance, while a man with two eyes has both methods and is likely therefore to make a more nearly accurate judgment.

Effect of the Atmosphere.—These two methods of perceiving distance are not very reliable beyond the distance of 100 feet, and indeed beyond 50 feet the judgment is not likely to be very accurate. But we need to judge of distances greater than this. When we look at a steeple or a tree a mile or more away, we judge of its distance by the sharpness or clearness of its outline. There is always more or less dust and water vapor in the atmosphere, which constitutes a haze, rendering the objects that are distant less distinct than those that are near. When we are fully acquainted with the atmosphere, we are not likely to make great mistakes in judging distance; but if the atmospheric conditions are unfamiliar, we may make serious errors. Nearly all persons from the Eastern states who go to the western plains or mountains experience considerable difficulty in estimating distances in consequence of the unfamiliarity with the atmospheric conditions.

Muscular Sense Indirectly.—Here the immediate

judgment is not made by means of the muscular sensation, but we have learned to interpret the sharpness of outline, and to estimate the haze in the air at first by means of it. So even here the muscular sense enters indirectly into the judgment of distance.

Shape.—We estimate the shape of objects in the same way. Shape depends upon the relative distance between different sides of the object, and the distance between any two points on an object is estimated by means of the muscular effort involved in moving the eyes from one point on the periphery of the object to another.

Size.—Size is estimated by the same means. The primary judgment in estimating size is the distance that the object is from us. Two objects that subtend the same visual angle will be judged of the same size if they are the same distance away; but if one is judged to be farther away than another, which distance as we have seen is primarily determined by the muscular sensation, the one that is farther away will be judged the larger.

Moon on the Horizon and Meridian.—To nearly all persons the moon appears to be larger when we see it rising at full, on the horizon, than when the same full moon appears on the meridian. There is a wide difference in the estimates of the apparent diameter of the moon by different persons. To the writer, the moon appears to be three or four feet in diameter when seen on the meridian, while on the horizon the same moon appears to be from 40 to 60 feet. Nearly all normal school students in the writer's classes assert that the

moon appears to be not more than a foot in diameter on the meridian and two or three feet on the horizon.

Distance of the Moon.—If the moon appears to be three feet in diameter on the meridian, it means that we estimate it to be at a distance of about 360 feet from us, approximately the distance of a short city block. The moon subtends an angle of about half a degree. There are 360 degrees in a circle, so it would require 720 moons to fill the circumference. If the moon appears to be three feet in diameter, the circumference of the circle would be 2,160 feet, the diameter about 720 feet, and the radius of the circle, which would be the distance of the moon, 360 feet. Similarly, if the moon appears to be 40 feet in diameter on the horizon, that is evidence that we judge it to be about 4,800 feet away from us, or slightly less than a mile.

Solidity.—We judge the solidity of an object primarily by means of the muscular sense, in passing our hands over it and around it. But later, and secondarily, we perceive solidity with the two eyes by means of binocular vision. If we look at a cylindrical post, whose diameter is not greater than the distance between the eyes, we shall be able to see half of the surface with one eye. But while one eye sees half of the surface, the other eye sees a somewhat different half; consequently the two eyes see rather more than half the surface, or they together see somewhat around and behind the objcet. It is this additional surface that enables us to perceive the post as solid.

Stereoscopic Pictures.—Stereoscopic pictures are made by taking two photographs from slightly different points, such that the two pictures will represent the images seen by the two eyes. Thus we shall experience exactly the same sensation that we do when we see the object with two eyes. The difference in the appearance of the images made upon the two eyes is very slight, and it probably requires considerable experience to enable us to interpret this slight amount of difference. The probability is that if a person were born blind, and acquired considerable intellectual culture before obtaining sight, that he would not perceive solidity or distance by sight until he had learned to interpret his impressions by means of the sense of muscular effort.

Lights and Shadows.—Much the larger part of our impressions of solidity, however, is derived not directly from binocular vision, nor muscular sensation, but even more indirectly from unconscious inference, by a judgment of light and shadow, represented by an object. When we look at a well painted picture it is the correct rendering of light and shade that gives us the impression of solidity. Originally we learned to interpret the appearance of the lights and shadows by means of the muscular sensation, but when we have once learned to recognize what our muscular sensations would be in the circumstances presented, we no longer need to experience the muscular sensation to perceive or infer the solidity.

Square Misjudged; S and 8.—If we look at a square

on the blackboard, it will seem to us that the vertical dimension is greater than the horizontal. This is true unless we know that the object is a square, and reason ourselves out of the impression. If we draw a horizontal line through the middle of the square, we shall perceive that the top half is larger than the bottom half. If we look at the letter S or the figure 8 we shall see that the top and bottom parts of the two printed impressions are equal; but if we turn the paper and look at the two characters upside down, we shall see that what was the bottom portion and is now the upper part is considerably the larger. The larger size of the bottom part is necessary if we wish to get the impression that the two are equal.

Framing Picture.—Similarly, if we wish to frame a picture so that the margin of matting at the top and bottom shall appear to be equal and give a symmetrical impression, the part at the bottom must be decidedly larger. A picture is not well framed if the part of the matting which shows at the top measures the same as that which is shown at the bottom.

Explanation of Space Illusions.—The explanation of these so-called illusions is not easy. It appears, however, to be found in the amount of muscular exertion required to turn our eyes throughout different portions of the field of vision. The greater portion of our seeing is done below the horizontal line. The muscles that move our eyes within that range are more frequently used and are really stronger than those which move them in the range above the horizontal position. It requires

a greater amount of muscular effort to raise our eyes through an arc above the horizontal line than it does to lower them through an arc below the horizontal line. Hence we judge that the top portion of an object is larger because we have expended a greater amount of muscular effort in causing our eyes to traverse the upper portion than we have in causing them to traverse the lower portion. This is emphasized also by the fact that when we compare two portions of an object, our eyes usually travel from the middle each way to the edges. We judge of the amount of distance by the amount of muscular sensation, or nervous energy expended, and consequently we make an incorrect perception.

Why Not See Things Inverted.—We are sometimes confronted with the question why it is that we do not see things upside down, since the image on the retina is inverted. The position of the image has nothing to do with the matter directly, since it is not the image that is perceived, but the object. There is no way by which a person is himself aware of the fact that an image has been formed on the retina, but the position of the object that is seen is determined by the direction in which the muscles must act in order to turn the eye to the top and the bottom. If the muscles need to pull the eye upward in order to see a particular point on the object or to cause the image of the point to fall on the fovea, that point is judged to be at the top, or above. If the muscles must pull the eye downward to see the point, that point is at the bottom, or below. So our judgment of the top and bottom of an object that is

perceived is determined by the muscular sensation.

Perception of Time.—All that we have said about the nature of space may with equal propriety be asserted of time. Time has been regarded as an intuitive idea, as a necessary form of thought, and as underivable from experience. It appears, however, that all of our ideas of time are derived from experience. Time is the abstract of the intervals between sequential events, as space is the abstract of coexistent potions.

No Time Sense.—We have no sense by means of which we perceive time directly, any more than we have for the perception of magnetism, or ether or electricity. But we can perceive the interval between events, and by a process of abstraction and generalization we arrive at our notion of time.

Pulsation of Consciousness.—We have within ourselves a time measure, although it is not a time sense. We experience a pulsation of consciousness, which is the interval that is required under ordinary conditions for an impulse to pass into, through and out of a brain center. It is nearly the interval the attention can be held upon a single aspect of an object. It is about the amount of the simple reaction time. It differs in different individuals, and is not constant in the same individual at different times. This pulsation of consciousness is the real, or specious present, and can not be described in any of its parts as either past or future. It is our immediate measure of time intervals.

The Primary Interval.—Our judgment of the time that elapses between two events is determined primarily

by this pulsation of consciousness. We later estimate the interval between other events by means of this pulsation of consciousness, and then employ these secondary measures as a means of measuring longer intervals. Heart beat, respiratory movements, times of getting hungry and other bodily functions may all of them be employed secondarily as means of estimating time.

Rhythm.—The pulsation of consciousness results in the acquisition of rhythm. By rhythm we mean the accented measure in which we walk or talk or think. The most common is the one-two rhythm, and is acquired not merely from the pulsation of consciousness, but by means of our movements. In walking there is an alternate one-two movement of the legs, and even in the movement of one leg there is the alternation of the press-swing that is the beginning of rhythm. We are assisted in the acquisition of rhythm by our sense of sight. Pendulums vibrate; trees sway; waves come and go; the arms swing in walking, and even the sounds of a bell and other noises that occur regularly bring the aid of hearing to rhythm acquisition.

One-two-three Rhythm.—The acquisition of a one-two-three rhythm is more difficult and comes mostly through hearing, although it may be learned by movement. There are fewer examples of one-two-three rhythm within our experience than of the one-two rhythm. The waltz movement is more difficult to acquire than is the march movement. When the one-two-three rhythm and the one-two rhythm have been acquired any other rhythm may be obtained by combination.

Importance of Rhythm.—All of our musical appreciation originates in rhythm, as well as the enjoyment of dancing, and a large part of the satisfaction derived from reading poetry. Hence it is that all teachers try to develop the idea of rhythm. With deaf children this is a difficult matter. Teachers of the deaf sometimes cause children to put their hands, or their teeth, on the top of a piano while it is played with a strong accent. Dancing, and especially the waltz movement, is taught laboriously and painstakingly as a means of inculcating the idea of rhythm.

Filled Time Longer.—Filled time seems longer than empty or vacant time. This is true notwithstanding the fact that absolutely vacuous time, such as we believe we spend when we are waiting for a street car, or lying on a sick bed, seems very long. When we look back at it afterwards, we see that it was not very long. The time that we call absolutely vacuous is that which is measured principally by the pulsations of consciousness, and as these are many, the time appears to be long; and as they are not very vivid, afterwards it seems to have been an illusion. When other events claim our attention, the pulsations of consciousness are overlooked.

Time to a Child and a Man.—A year seems much longer to a child than it does to a man. The years seem to become shorter as the person grows older. This is an universal experience, and seems to be accounted for by the fact that a year represents a different proportion of the person's life. To a child of six, a year represents one-sixth of his whole life, or perhaps a third of the only

life that he can remember and compare with it. To a man of 40, one year is only one-fortieth of his existence. Hence, in comparison, the year seems much shorter to him.

DEFINITIONS.

Intuitive Idea—An idea furnished by the mind itself, not derived from experience.

Distance—The relation between two points, or positions.

Space—A real existence, our knowledge of which is derived from an abstract of coexisting positions and generalized distances.

Time—A real existence, our knowledge of which is derived from an abstract of sequential events, and generalized intervals.

Pulsation of Consciousness—The time required for a nervous impulse to pass into, through and out of a brain center.

Specious Present—The time of the pulsation of consciousness that is in progress at any one instant.

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